70TH CONGRESS } 2d Session } HOUSE OF REPRESENTATIVES { DOCUMENT No. 573

RELATION OF FORESTRY TO THE CONTROL OF FLOODS IN THE MISSISSIPPI VALLEY

MESSAGE FROM THE PRESIDENT OF THE UNITED STATES

TRANSMITTING

COMMUNICATIONS FROM THE SECRETARY OF AGRICULTURE SUBMITTING REPORTS WITH REFERENCE TO THE RELATION OF FORESTRY TO THE CONTROL OF FLOODS IN THE MISSISSIPPI VALLEY

FEBRUARY 11, 1929.—Referred to the Committee on Flood Control and ordered to be printed, with illustrations

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1929

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MESSAGE

To the Congress of the United States:

I am transmitting herewith for the information of the Congress communications from the Secretary of Agriculture, dated June 4, 1928, and February 9, 1929, submitting reports with reference to the relation of forestry to the control of floods in the Mississippi Valley. These reports have been prepared in compliance with the provision contained in section 10 of the act of Congress approved May 15, 1928, for the control of floods on the Mississippi River and its tributaries, and for other purposes.

CALVIN COOLIDGE.

THE WHITE HOUSE,
February 11, 1929.

LETTERS OF TRANSMITTAL

Department of Agriculture,
Washington, June 4, 1928.

Dear Mr. President: In compliance with the terms of your letter of June 1, I have the honor to submit herewith an initial report by Associate Forester E. A. Sherman with reference to the relation of forestry to the control of floods in the Mississippi Valley. Some mimeographed copies of this report have been distributed but, in view of the importance of the subject matter in relation to the general problem of flood control on the Mississippi River, it is believed that the publication and more general distribution of the report would be in conformity with the provision of the act of May 15, 1928.

In compliance with your letter this department will at once proceed to make such additional studies and to collect such additional data with reference to the relation of proper forestry practice to flood control as prove to be practicable with the present appropriations and personnel of the department and will submit the results of such studies as soon as they take definite form.

Sincerely yours,

W. M. Jardine, *Secretary.*

The President,
The White House.

Department of Agriculture,
Washington, D. C., February 9, 1929.

Dear Mr. President: Under date of June 4, 1928, certain information with reference to the relation of forests to the control of floods in the Mississippi Valley was transmitted to you. As this material covered only in part the data called for under the last provision of section 10 of the act for the control of floods on the Mississippi River and its tributaries, and for other purposes, approved May 15, 1928, the promise was made that this department would at once proceed to make such additional studies and to collect such additional data with respect to the relation of forests to flood control as were practicable. This has been done and I have the honor to submit herewith a further report upon this subject, prepared under the direction of Associate Forester E. A. Sherman. This report indicates the need of still further detailed study not possible with present personnel and funds.

However, the added study of the problem has brought to light some startling facts worthy of your closest attention for they show that the forests of the Mississippi watershed were responsible for a

reduction in the possible flood crest of nearly 15 inches. Furthermore, were all the forests of the Mississippi Valley properly protected and managed in accordance with established forestry principles and practices, a further reduction in possible flood crests of 55 inches would be possible. According to the data of Maj. Gen. Edgar Jadwin, this restraining effect would be equivalent to the storage capacity of some 4.6 reservoirs each with a capacity of 10,000,000 acre-feet.

Thus the results even when based on acknowledged incomplete and conservative data, are of such significance that it does not seem possible that the part the forests play in the control of floods can be longer ignored. Certainly it would seem that any plan of the river control that does not include forestry as an auxiliary measure would overlook an important aid in the control of floods at their source.

The recommendations of the department included in the accompanying report indicate the way in which the forests may be made to do their part, and the department will, of course, go as far as it can in its endeavor to improve the situation.

Very sincerely,

W. M. Jardine, *Secretary.*

The President,
The White House.

PROTECTION FORESTS OF THE MISSISSIPPI RIVER WATERSHED AND THEIR PART IN FLOOD PREVENTION

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PROTECTION FORESTS OF THE MISSISSIPPI RIVER WATERSHED AND THEIR PART IN FLOOD PREVENTION

By E. A. Sherman, *Associate Forester, Forest Service*

FOREWORD

In times past, even before the white man had disturbed the heavy forests of the Mississippi River Basin, floods were known there. With the settlement of the country, forest fires, overcutting, and the abuse of forest and other lands have served to increase the possibility of floods and their severity and the amount and extent of erosion. Forests have a part in the general flood and erosion problem, and it is well that this part should be recognized. It should be emphasized, however, that it is not proposed that forestry should supplant engineering works in flood control, but that forestry should supplement whatever means of artificial control may be adopted by engineers.

A program of sound forestry development that will permit the forests of the Mississippi River Basin to exert their greatest influence on the regulation of water flow should include protection of all forest lands against fire, the reforestation of all denuded lands unsuited for agriculture, the extension of proper forest practices to all forest lands, the public ownership of particularly critical areas, the continuance of existing public forests, and placing the public grazing lands under management. This program should be supplemented by additional research and investigation of ways and means for the better handling of forest lands as a means of controlling erosion and minimizing floods.

INTRODUCTION

The Mississippi River, from time immemorial and until prevented by artificial barriers, was accustomed every few years to inundate about 30,000 square miles of land. This ancient flood plain, which under levee protection had been developed into a very rich territory, was the scene of the flood of 1927 (fig. 1), the greatest physical disaster in American history. Uncontrollable waters inundated about 18,000 square miles of country and dispossessed about 750,000 people of their homes, some temporarily and some permanently. The property loss was appalling. Fortunately, about 12,000 square miles of the richest portions of the ancient flood plain, as well as the city of New Orleans, were saved by protecting levees.

This disaster removed every doubt that the problem of controlling floods on the Mississippi River is a national responsibility, challenging the best efforts of every public agency. The Forest Service responded by promptly undertaking an investigation of the forests and forest lands of the Mississippi watershed to determine their relation to the great flood problem and the measure in which they might be made to contribute to its solution. The purpose of this publication is to present in broad outline the fruits of that study.

The study did not include the special field of the engineer who seeks to control floods by such structures as levees, spillways, and reservoirs, a field already filled by the Mississippi River Commission and the engineers of the War Department. It did include an investigation of land-surface conditions, particularly in forest regions, with a view to determining if better land use might lower flood crests and reduce flood hazards. The activities recommended as a result of this study are proposed as supplementary to engineering works and in no sense as an alternative.

SCOPE OF STUDY

While this is primarily a report on the protective influence of Mississippi Valley forests, the study upon which it is based necessarily covered surface conditions and land use generally. The starting point was the self-evident fact that the condition of the land surface has a direct influence on the amount of water held and retained by the soil, on the time and rapidity of run-off, and on the silt content of streams contributing to floods, as well as on the volume, velocity, and turbidity of the water itself. It follows that any form of land use which affects the condition of the surface has a direct bearing on the run-off from that land.

One of the important uses of land surface is for the production of forest crops. Land so used constitutes about one-fifth of the total land surface of the basin. The forests usually occupy regions of relatively heavy rainfall, and embrace a large percentage of the areas of roughest topography and greatest elevation. These are, generally speaking, the regions from which run-off is most rapid. Such forest lands doubtless play a relatively larger part in the flood problem than mere area would indicate. Determining what areas are now in forests or could advantageously be reforested and estimating their influence on run-off and stream-flow condition come within the field of Forest Service responsibility. This study was limited to that field, excepting as studies of range, pasture, agricultural, and even barren lands were necessary to determine whether or not the extension of forests to lands of some other class was practicable or desirable. The field of this study obviously covered activities and conditions which are factors entering into the flood problem but which do not usually come within the field of the construction engineer's observations and operations.

MISSISSIPPI WATERSHED ALWAYS LARGELY NONFOREST LAND

The Mississippi Basin has always been conspicuous among the great river basins of the world for its large percentage of nonforest

FIGURE 1.—Topography and flood plain

land. (See fig. 4.) Comparatively speaking, it has always been a lightly forested country. Originally 60 per cent, it is now 80 per cent nonforest land.

Also floods in the Mississippi have been recorded as far back as history reaches. De la Vega, in describing the difficulties encountered by De Soto's men when, following their leader's death, they determined to build boats and descend the Mississippi, says:

> Then God, our Lord, hindered the work with a mighty flood of the great river, which, at this time, began to come down with an enormous increase of water, which in the beginning overflowed the wide level ground between the river and the cliffs: then little by little it rose to the top of the cliffs. Soon it began to flow over the fields in an immense flood, and as the land was level, without any hills, there was nothing to stop the inundation. The flood was 40 days in reaching its greatest height, which was the 20th of April, and it was a beautiful thing to look upon the sea where there had been fields, for on each side of the river the water extended over 20 leagues of land, and all of this area was navigated by canoes, and nothing was seen but the tops of the tallest trees.

The report on this river submitted in 1861 to the Bureau of Topographic Engineers, War Department, by A. A. Humphreys and H. L. Abbott lists floods as having occurred in 1718, 1735, 1770, 1782, 1785, 1791, 1796, 1799, 1809, 1811, 1813, 1815, 1916, 1823, 1824, 1828, 1838, 1844, 1847, 1849, 1850, 1851, 1858, and 1859. The serious floods of more recent times have been in 1882, 1892, 1897, 1898, 1903, 1907, 1912, 1913, 1916, 1920, 1922, and 1927. The highest recorded stage of water previous to 1927 on the lower portions of the river, was reached by the flood of 1922.

It is difficult to make a fair comparison as to severity between the later floods and those of earlier times. Before the construction of levees high water every year inundated a considerable area of low country. Naturally, as the levee system has been constructed and the stream confined, the tendency has been for the waters to reach higher and higher levels. Even without any increase in precipitation or run-off, this would be the natural result of excluding the flood waters from lands formerly subject to overflow.

It was early evident that for reliable information on how run-off was being influenced by the presence or absence of forests, a study must be made in detail of the actual source of run-off. The regimen of a stream at any given point is a composite of all factors influencing run-off from the entire area above. Influences constructively beneficial on one drainage unit may be neutralized by destructive factors on some other contributing stream. Obviously the flood waters as they reach the leveed region are a mixture coming from all kinds of watersheds, some well protected, some poorly, some not at all.

The total area of the Mississippi River Basin within the United States, including the lands subject to inundation, is 1,231,492 square miles. So vast an area is hard to treat as a unit. Diversity of climate, cover, and human use adds complexity to immensity. Although only about 244,000 square miles of forest lands, or about 20 per cent of the total area, are involved in the problem, these forest lands are distributed throughout the humid portions of the entire basin. Furthermore, the use of forest lands must be coordinated on a practical basis with the use of other kinds of lands adjoining.

Though the source of the great volume of water in the 1927 flood was largely the run-off from heavy and prolonged rainfall in the lower

central valley, at the same time a factor to be reckoned with at all times is the contribution which each individual drainage unit may reasonably be expected to make to the main flow at any given time. For a thorough understanding of the problem it was therefore necessary to consider the watershed both in detail and as a unit.

IMPORTANT DATA LACKING

In the course of this study it was found that reliable data essential to accurate determination were in many instances nonexistent. Topographic maps, soil maps, forest maps were too often lacking for important regions.

It seems fundamental to a carefully planned study of land use, covering long-time periods, that there be available accurate data for each of the major tributaries of the river showing annual and periodic run-off and total and periodic volumes of silt content. Dependable data on silt content were woefully lacking. Determinations made many years ago could not be checked against similar data of more recent date because recent measurements had not been made. A complete record of stream-flow measurements and silt determinations at some point below Cairo and on each of the principal tributaries entering the Mississippi River below that point and covering the past four decades would have been of inestimable value in this study. Such records beginning in 1928 would become increasingly valuable from year to year. Regardless of any light the data might throw on the flood problem, it would give a splendid check on the problem of land use and the trend of soil erosion. By means of such records it would be possible at any time to determine whether or not efforts in reforestation, forest protection, contour plowing, and farm terracing were reducing the burden of silt in the river at Cairo or in any of the tributaries under observation. For that reason the absence of such data is noted in this report, and the desirability of securing accurate information of this kind is given a place in the conclusions and recommendations.

MAJOR BASINS OF THE MISSISSIPPI

A systematic investigation of the forested watersheds of the Mississippi Valley and their relation to the floods of that river required a somewhat arbitrary subdivision of the entire region, first into major basins and then into individual drainage units.

The subdivision into six major basins which was finally adopted for this study is shown in Figure 2. This subdivision appears to be generally followed, with perhaps some minor modifications, by all agencies in studying the Mississippi flood problem. It follows largely the classification used in the report of 1861 by Humphreys and Abbott. These authors, however, treated the St. Francis River and the Yazoo Basin each as distinct major basins. The subdivision of the major basins into principal drainage units used by the Forest Service in making the study, with the areas of each major basin and each drainage unit thereunder, is shown in Table 1.

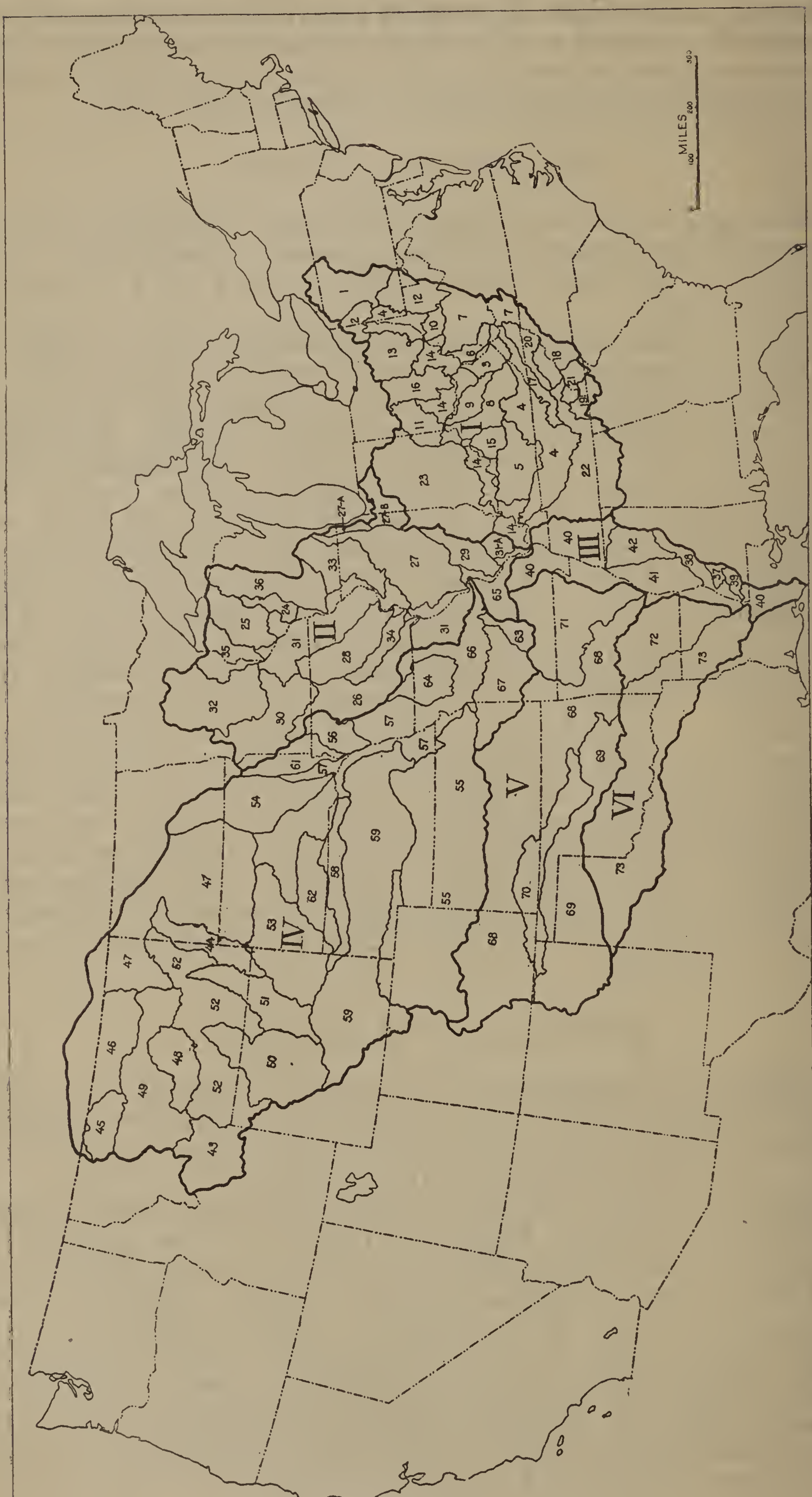

FIGURE 2.—Index of major and minor basins

TABLE 1.—*Mississippi River drainage—Areas of major and minor basins within the United States* [1]

Basin and river No.	Area
	Sq. miles
OHIO RIVER	
1. Allegheny	11,683
2. Beaver	3,182
3. Big Sandy	4,259
4. Cumberland	17,939
5. Green	9,329
6. Guyandot	2,354
7. Kanawha	12,303
8. Kentucky	6,945
9. Licking	3,742
10. Little Kanawha	2,382
11. Miami	5,352
12. Monongahela	7,339
13. Muskingum	8,052
14. Ohio (direct)	26,239
15. Salt	2,986
16. Scioto	6,361
Tennessee	40,423
17. Clinch	4,278
18. French Broad	5,052
19. Hiwassee	2,702
20. Holston	3,826
21. Little Tennessee	2,549
22. Tennessee (direct)	22,016
23. Wabash	32,912
UPPER MISSISSIPPI RIVER [2]	
24. Black	2,920
25. Chippewa	9,379
26. Des Moines	14,184
27. Illinois	21,631
27a. Des Plaines	1,425
27b. Kankakee	5,188
28. Iowa-Cedar	12,496
29. Kaskaskia	5,812
30. Minnesota	16,264
31. Mississippi (direct, below St. Paul and above junction with Missouri on west side and above junction with Ohio on east side)	34,300
31a. Big Muddy	2,402
65. Mississippi (direct, on west side between Missouri and Ohio River junctions)	5,748
32. Mississippi (above St. Paul)	20,449
33. Rock	10,765
34. Skunk	4,323
35. St. Croix	7,664
36. Wisconsin	11,903
LOWER MISSISSIPPI RIVER [2]	
37. Bayou Tallahala	1,046
38. Big Black	3,559
39. Homochitto	1,261
40. Lower Mississippi (direct) [3]	33,002
LOWER MISSISSIPPI RIVER—continued	
41. Yazoo (bottom lands)	7,324
42. Yazoo (highlands)	6,496
MISSOURI RIVER	
43. Jefferson-Madison-Gallatin Forks	13,949
44. Little Missouri	9,351
45. Marias	7,079
46. Milk	15,042
47. Missouri (direct, Cheyenne River to mouth of Milk River)	52,703
48. Musselshell	9,606
49. Upper Missouri (above Milk River)	26,827
Yellowstone	70,172
50. Big Horn	23,057
51. Powder	13,480
52. Yellowstone (direct)	33,635
53. Cheyenne	25,510
54. James	20,715
55. Kansas	59,710
56. Little Sioux and Floyd	5,801
57. Missouri (direct, Cheyenne River to Missouri State line)	31,428
58. Niobrara	11,875
Platte	89,877
59. Platte (main)	65,832
60. South Fork Platte	24,045
61. Sioux	8,212
62. White (S. Dak.)	10,209
63. Gasconade	3,540
64. Grand	7,831
66. Missouri (direct, in Missouri)	17,232
67. Osage	14,967
ARKANSAS-WHITE RIVER	
Arkansas	160,664
68. Arkansas (direct)	95,367
69. Canadian	47,552
70. Cimarron	17,745
71. White	27,678
RED RIVER-OUACHITA	
72. Ouachita	18,643
73. Red	69,548
SUMMARY BY MAJOR BASINS	
Ohio	203,782
Upper Mississippi	186,853
Lower Mississippi	52,688
Missouri	511,636
Arkansas-White	188,342
Red-Ouachita	88,191
Total	1,231,492

[1] Based on planimetric measurements of U. S. Geological Survey maps applied to the actual surveyed areas of the States. Canadian drainage of 12,934 square miles in the Missouri Basin is not included.
[2] The drainage of the Mississippi River proper, excluding the Ohio, Missouri, Arkansas, and Red River Basins, is divided at Cairo, Ill., into upper Mississippi and lower Mississippi.
[3] Includes 5,441 square miles of indeterminate drainage such as the Atchafalaya River and other interconnected waterways in southern Louisiana.

For a proper understanding of the protective influence of the forests of the Mississippi River drainage, their relationship to floods, and their possibilities and potentialities as factors in stream-flow regulation, due consideration must be given to certain well-recognized characteristics of running water and the relationship which

forests bear to soil and water conservation.[1] It is commonly stated as a law of physics that the erosive or abrading power of a stream varies as the square of its velocity. For example, if the velocity of a stream is increased ten times, its erosive power is increased one hundred times. It is also commonly stated as an immutable law that the transporting power of water varies as the sixth power of its velocity. For example, if the velocity of a stream is increased ten times its transporting power is increased one million times. Le Conte determined by experimentation that a current having a velocity of 2 miles an hour will move in its channel fragments of stone the size of a hen's egg, weighing about 3 ounces. From this he calculated that a current with a velocity of 20 miles an hour will carry bowlders weighing 100 tons. This is doubtless movement along the bottom of the channel.

It is the understanding of the writer that such so-called "laws" are, owing to certain variable influencing factors, mutable, although the examples cited of the comparative transporting power of river currents furnish a fair criterion of probable results.

FORESTS IN RELATION TO EROSION AND STREAM FLOW

It does not require demonstration or the introduction of scientific data to sustain the self-evident fact that water falling on steep lands tends to run off rapidly. The examples just cited show that erosion is tremendously increased by rapidity of run-off. It follows that for any given type of soil the steepest lands are most subject to erosion. Therefore it is upon steep rough lands that forests as an erosion-preventive factor are most important.

The forest breaks the impact of rainfall and retards the hasty run-off in the following way: (1) Its canopy of leaves or needles, with supporting twigs, branches, and trunks, catches the first impact of precipitation and absorbs the first shock of its fall. Instead of beating directly upon the earth the raindrops are shattered and either evaporate or settle slowly in the form of mist, or reassemble and trickle down the trunk and branches, or drip to the ground. The surface of the forest floor frequently has an understory of young growth or shrubs, vines, and other vegetation which may again break the impact of fall. Under all these, at least in the typical virgin forest of the Temperate Zone, is usually an accumulation of twigs, leaves, needles, moss, and other vegetative growth forming an absorptive layer or carpet of humus often 6 inches or more in depth. Lying as it does, shielded from the wind and sun,

[1] Le Conte, Joseph. Elements of Geology. Ed. 5. 667 p. illus. N. Y., 1903. Page 11, "Law of variation of erosive power.—The erosive power of water, or the power of overcoming cohesion, varies as the square of the velocity of the current." Pages 19–20, "By mathematical analysis the law is determined. That is, the transporting power of a current or the weight of the largest fragment it can carry varies as the sixth power of the velocity."

Gibson, A. H. Hydraulics and its Application. Ed. 3. 801 p. illus. N. Y., 1905. Page 322, "While the erosive power of water varies as the square of its velocity, its transporting power, or the power to move bowlders, etc., which may lie in its path, varies approximately as v^6."

Gilbert, G. K. The Transportation of Débris by Running Water. U. S. Geological Survey. Professional Paper No. 86. 263 p. illus. 1914. For a careful study, having for its purpose the empirical determination of the relation which the load of solids swept along the bed of a river bears to its velocity and other important factors of control, the reader is referred to this professional paper.

this deposit of humus is protected from rapid surface evaporation, while affording most favorable undersurface conditions for the percolation of moisture into the soil.

This layer of humus varies quantitatively and qualitatively, according to type, location, and use. Qualitatively the humus from the conifers is more effective as a moisture absorbent than that from hardwoods. Quantitatively it is greatest in the spruce-balsam-white cedar-hemlock type of forest prevalent at the higher elevations or in northern forests, and smallest in hardwood regions of the South, where the practice of burning the woods annually is prevalent and where decomposition of vegetable litter is most rapid and complete. Under favorable conditions the layer of humus in a well-managed, well-protected forest of the spruce-balsam-white cedar-hemlock type may be as much as 6 inches deep. Varying with the type of forest, the age class of the stand, the quality and kind of site, and the degree of protection and management, the depth of the humus will shade down from 6 inches to the comparatively small accumulation of a single season, which becomes nil immediately following a fire.

Under ordinary rainfall conditions this humus is capable of absorbing and holding a considerable quantity of water for evaporation, percolation, or transpiration. The amount of moisture thus actually absorbed varies; but a quarter of an inch in depth of rainfall for each inch of depth of humus of leaf litter is known to be conservative. This ratio has been used in all calculations in this report unless otherwise specified. In addition to the moisture absorbed, the forest retards or holds in temporary restraint an amount of water often many times as great as the volume actually absorbed. The process of absorption itself is not instantaneous. The forest floor does not expend its full absorptive influence on the first brief shower, but the process continues over a considerable period. Even in entire immersion about 24 hours are required to complete saturation, and under rainfall conditions absorption continues for 48 hours.

While moisture is being absorbed by the mat of humus, the forest-crown cover and forest litter also hold back or retard the run-off of water not actually absorbed. Through such a combination of influences a forest having a good crown cover and a good blanket of humus can be relied upon to absorb and retain for later and more gradual and beneficial transmission a very great part of even an unusually heavy rainfall. Instances are recorded in which a forest with deep humus or leaf litter did not give off any water in the form of surplus run-off even on the steepest slopes after a rainfall of 2.4 to 2.8 inches. This, however, is beyond what can ordinarily be relied upon.

During an extended period of rainfall the quantity of water diverted from run-off by being absorbed by the mat of humus is materially supplemented by the amount of evaporation, percolation, and transpiration taking place during the same period. In addition the forest operates much like a check dam through retarding run-off by mechanical obstruction. The rainfall which is not at once absorbed or permanently impounded sinks into a tangled mass of accumulated vegetation, fills up its interstices, and slowly searches

out through a maze of moss, needles, leaves, twigs, and other vegetative growth the path of least resistance down the slope. In this way rainfall, which would otherwise reach the nearest brook in a few hours, may be delayed for days or even weeks, may finally reappear in some spring, or may be taken up by some plant and again transmitted to the atmosphere without ever contributing to stream flow.

The forest, its understory of brush, and the blanket covering of humus not only break the impact of precipitation and hold in temporary suspension a considerable volume of water, but their combined influence tends to make the underlying soil and subsoil more receptive to percolation. The soil is loosened by the roots and shielded by brush and trees from being baked by the sun and packed by the tramping of stock. Accretions of humus in the soil itself also increase the permeability and water-retaining capacity of the soil. The mulch covering also keeps the soil moist so that the forces of absorption as well as gravitation may operate most effectively in helping to transmit to the underlying soil the excess moisture held in temporary captivity.

The forest, the brush, and the humus layer also tend to conserve precipitation in the form of snowfall by protecting the surface of the soil from freezing. Rain falling on ground already solidly frozen, or water from melting snow on frozen ground, runs off as though from a tin roof. On the other hand, even in midwinter after the ground in the open is frozen solidly, moisture from melting snow or rain can usually find its way through open spaces of the coarse top cover of forest litter into the protected layers below where it can be finally taken up by the soil.

The presence of forest cover on a given watershed may under certain conditions increase the run-off from some limited area during the spring flood period. This can happen when an unseasonably warm heavy rain encounters a winter's snow accumulation. There is, of course, a limit to the capacity of forest cover to retain moisture and retard run-off. When this limit is reached a high-water stage follows. Had the forest been cleared away and the bare soil exposed to frost, wind, and sun most of the winter's snowfall would have been dissipated and the freshet limited in volume largely to the immediate rainfall, little if any of which would have been retained by the frozen ground. The resulting flood, while much more flashy than from a forested watershed, might not reach even as high a stage and would be of very brief duration. However, an increase in flood flow caused by forest protection is the rare exception, and over a large area would be offset by beneficial results from other drainage units. The general tendency of the forest cover is to ameliorate freshet condition, and over any large area the general tendency always prevails—the peak of the flood is not so quickly reached; the run-off is spread over a longer period of time; erosion is reduced; and damage by silting and washing is correspondingly lessened.

In conformity with the known conduct of running streams, as stated in the opening paragraph of this section, forests reduce the eroding and transporting power of water by reducing the rapidity of run-off. In addition they are a direct physical obstacle to erosion because they have large, strong, well-anchored roots which hold soil

subsoil, and rocks firmly in place. A forest with a good understory of brush and a deep layer of humus is undoubtedly the best conservator of soil. Not only is the loss held to the negligible quantity removed by percolation, but actual additions of fertile material are made.

This factor of erosion is exceedingly important in flood-control work. Zon called attention to this fact in the final report of the National Waterways Commission, page 246, saying:

> Erosion has a bearing on the height of flood water in the river, since sediment carried by the rivers and the coarser detritus brought down by mountain streams often increases stream volume to such an extent that the height of the water is raised far beyond the point it would reach if it came free of detritus and sediment.

Not only does the presence of sand and gravel in the water increase the volume of the flood and raise its height, but in addition such abrasive material furnishes teeth to the freshet and enables it to tear up the earth, wear away embankments, and carry off accumulations of soil and other material otherwise safe from the ordinary attacks of flood waters. Erosion fattens as it feeds. Its progress is accelerated by its spoils of victory. The first few cubic yards of sand that enable the stream to wear away the protecting covering of sod from an exposed embankment may expose a thousand cubic yards of similar material to easy capture by the flood waters that follow.

The terrific power of mountain freshets has been pointed out by the famous French engineer, Demontsey, who found that one such torrent brought down, after one storm, in 85,000 cubic yards of water, over 221,000 yards of detritus, or more than two and one-half times its own water volume. Those who witnessed the havoc wrought in Pueblo, Colo., by the flood at the headwaters of the Arkansas River realize the destructive power of liquid mud. The Mississippi River in full-flood flow fortunately does not even remotely approach the speed of a mountain torrent. It would not, therefore, be capable of bearing so great a percentage of silt as a swifter stream. It is regretted that this study failed to unearth any reliable figures of recent date on silt content. Figures giving averages over long periods and for varying conditions of flow are obviously no index to actual silt content at flood crest, which is the critical point. Available data seem to indicate that the waters of the Missouri River at full-flood stage may contain as much as 3 per cent foreign matter. No estimate is attempted as to the probable silt content of the recent Mississippi flood at crest. This much, however, is certain—the country would be much richer and much better off if the eroded soil, the amount of which is known to have been great in the aggregate, though it may not have made up a large percentage of the flood content, had remained in place undisturbed.

Forests are not the only safeguards against erosion. Any vegetative cover has a tendency to retard run-off and check erosion. A good brush cover or a bluegrass sod is very much better than an open stand of timber which has been heavily grazed or through which a fire has recently run. However, the combination of trees, undergrowth, and forest litter which is secured under adequate fire protection and forest management, is best for critical areas—that is,

areas which, owing to natural features, are in danger of extensive washing. The canopy is most complete, the humus protection most thorough, and the roots strongest. It is always recommended for permanent protection purposes rather than brush or vines, for the reason that it is of value not only as a conserver of soil but for its wood crop. Tree planting to prevent erosion or for water conservation is, of course, not recommended for fields which can be profitably plowed and cropped without destructive soil washing. Nor are forests recommended for the more moderate slopes with soil which permits the establishment of a good grass cover sufficient to prevent destructive erosion and where the economic value of such cover equals or exceeds that of the forest. A good grass cover, where it can be secured and maintained, is an excellent safeguard against erosion except on the steepest slopes. As a factor in water storage or regulation, however, it does not compare with a well-managed forest.

The question of whether or not total run-off is increased or diminished by the presence of forests is one which does not admit of a categorical answer. The character of soil, the gradient, and the time, duration, quantity, and form of precipitation, as well as the character of the cover, all enter into the equation. Obviously, the ratio of total run-off to precipitation will be greatest where the slope is steepest, the soil most impervious, and vegetation most scanty. In such a case the maximum run-off occurs at once.

Usually immediate run-off is not desirable. Ideal conditions are usually found in regularity of flow, regularity at least during the period of beneficial use, and sufficient to avoid an embarrassing surplus. In some cases, such as on a watershed which is a source of water supply for irrigation, power, or domestic use, the maximum sustained volume of run-off is desirable—the greater the supply the larger the acreage irrigated, the greater the power development, or the more generous the domestic supply.

Trees consume water. A rapidly growing forest may during the year consume and transmit into the air a volume of water equivalent in depth to 12 inches over its entire area. On rocky slopes, upon which, through generations, the forest has spread its carpet of humus to hold in its store of moisture and to help secrete water in crevices where it may be reached by the searching tree roots and used in plant growth, the forest obviously uses moisture which otherwise would have contributed to immediate run-off. But this water is only used; not destroyed. In the atmosphere it is again available for precipitation.

The flood problem is measured by the volume of run-off. Only a part of the total precipitation on any watershed ever appears as run-off. Necessarily, that part of precipitation which passes into the atmosphere, either by evaporation or transpiration, can not appear in stream-flow measurements without again being deposited in some form of precipitation. On the other hand, that part which passes into the soil as percolation must eventually appear as run-off unless evaporated or taken up in plant growth.

In the study of the relation of forests to stream flow, an important fact to keep in mind is the wide difference between the total

precipitation and total run-off of any watershed. Also the fact that the ratio of the latter to the former varies widely for different watersheds. Something very important happens after the water reaches the earth, but before it reaches the river. This "something" is the result of the working of three natural phenomena—transpiration, percolation, and evaporation. The two first do not greatly influence the volume of water after it once reaches a stream in the form of run-off, but the last continues its pursuit of moisture, even to the sea itself.

Transpiration and percolation are greatly stimulated by plant growth. This applies to forests, particularly as to percolation. Forests retard evaporation from the soil under certain conditions, but this is more than offset, so far as immediate run-off is concerned, by transpiration and percolation.

If the value of forests as stream-flow regulators and flood-preventive factors were determined by the ratio of their water-storage capacity to the total annual precipitation, such value would be relatively very small. However, such a comparison does not give a rational basis of measurement. Floods are created only by actual run-off. Therefore the ratio of storage to run-off is a better index of flood-prevention service. [It seems desirable to illustrate the importance of this point by calling attention, out of its otherwise natural order, to the fact that of the total precipitation falling annually on the 511,636 square miles of the Missouri River watershed only 10 to 15 per cent (authorities differ, but 15 per cent is probably the better figure) ever reaches the Mississippi. The other 85 or 90 per cent is transmitted to the atmosphere by transpiration or evaporation, minus such minor quantities as may possibly be retained by some chemical process or combination.]

It is this remaining percentage which appears as run-off that contributes to the flood problem, and it is this remnant of the total for each watershed that may be in part regulated or controlled by well-managed protection forests. The ratio of run-off to precipitation is much larger for the other major basins of the Mississippi system than for the Missouri (primarily because both are higher—the spread between the two does not vary so much under similar climatic conditions), but in every case evaporation and transpiration are important factors in disposing of the total supply of water. The average run-off for the various parts of the Mississippi Valley region is shown graphically by Figure 3.

The wide difference between total precipitation and total run-off from the Missouri watershed is extremely interesting. Since that watershed is neither a lake which is increasing in size nor a shrinking desert, it must be that the 10 or 15 per cent of precipitation which the river carries in annual run-off balances the watershed's moisture account with outside sources. This fact, together with the known fact that plant life draws from the soil and returns to the atmosphere for reprecipitation considerable quantities of moisture which would otherwise have contributed directly to stream flow, suggests the possibility of increasing precipitation by encouraging vegetative growth. By irrigation, which means the recapture of moisture from run-off and its return to the soil for redispersion through evaporation, tran-

spiration, and percolation, water may be used repeatedly. It is indestructible. By such methods of recapture and use over a period of years the water capital of a region may be greatly increased. These possibilities and their climatic consequences open a field of speculation, which, however attractive, is beyond the scope of this report.

PROTECTION FORESTS, A PUBLIC NECESSITY

The influence of forests in retarding run-off and thus diminishing the destructive power of floods, and the value of forests in binding soils and preventing erosion have resulted in many forest areas in civilized nations being established as protection forests and placed

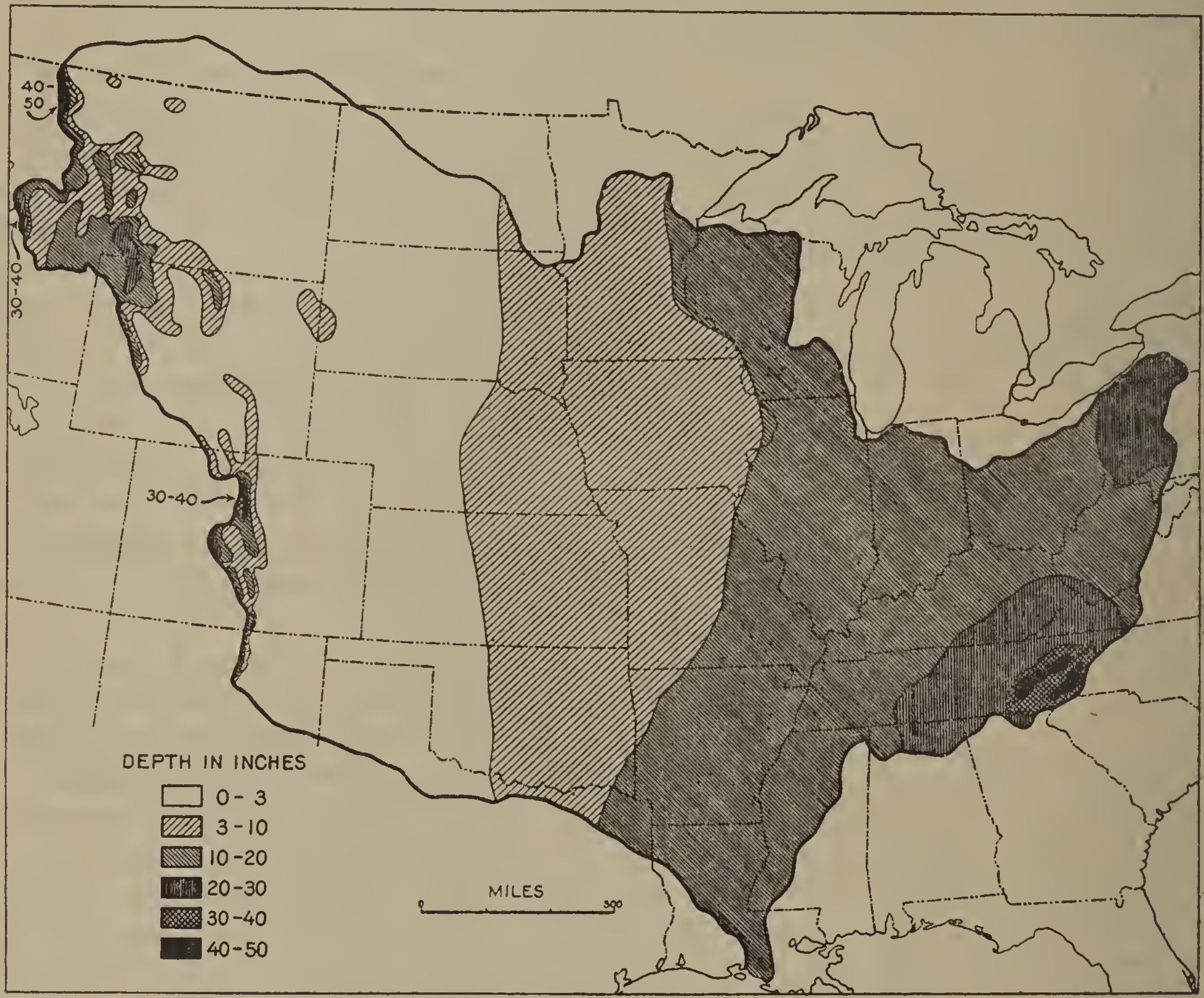

FIGURE 3.—Average annual run-off

under public control. These are largely in mountainous regions where, by reason of the nature of soil, topography, and climate, conditions causing accelerated run-off are most critical and most apt to result from ordinary private use of the land surface.

The use to which any forest area is put has a direct bearing upon its effectiveness as a protection forest. Its protective influence may be injured by the character, extent, or method of timber cutting, by the season and intensity of grazing, or by any other kind of use. The private owner is interested in using the forest to produce revenue rather than public benefits. For this reason, public ownership has been found to be the only practicable means of securing the highest use of forests where the protective function is so important that other uses, such as grazing and timber cutting, must be subordinated to protection.

Self-preservation requires that the public step in and acquire rough-broken lands where the destruction of forests or failure to maintain good forest conditions menaces interests of far-reaching importance. From the standpoint of a future national timber supply to be derived from our great commercial forests, the public interest may be safeguarded by Federal cooperation in fire control and leadership in forest management. The private incentive of revenue production will be served by securing the maximum productivity of the lands. Thus far self-interest and public interest travel one road. But where protective values are outstanding, as they are in most mountainous regions, a large measure of public ownership is a public necessity.

Public ownership of nonagricultural forest land on important watersheds is the logical outcome of the free play and development of natural economic laws and forces. The private owner of forest land in steep, rough regions can not be expected to manage his property for the public benefit when that means loss of revenue or increased expense. Conversely the owner of properties which may be injured by the misuse of such land can not safely rely upon the owner of the forest to give other lands contributory protection. Consequently, where widely scattered but important interests may be jeopardized by unwise use of land, the only fair and safe course is for the public to step in and take charge of the key property under terms and conditions fair to the original owner.

France, Germany, Switzerland, Austria, and Japan have each recognized the special function of the protection forest, and each places such areas under public control. This principle has been carried farthest in Japan where, owing to the mountainous character of the country, it was most urgently needed. In that little nation a total of 4,534,335 acres in 353,549 parcels has been placed under public control as protection forests. Protection forests in Japan are established against soil erosion, for water supply, against sand shifting, against wind, against tides, against floods, against avalanches, against rolling stones, for fisheries, for public health, for guiding navigators, and for scenery. However, over 90 per cent of the total area comes within the first two classes.

Protection forests are also maintained by our own Government. The act of 1897 (30 Stat. 11) authorized the President to establish public forests "for the purpose of securing favorable conditions of water flows, and to furnish a continuous supply of timber for the use and necessities of citizens of the United States." The same principle was recognized by the Weeks law, passed by Congress March 1, 1911 (36 Stat. 961). Under this act there had been expended by the Federal Government, under the direction of the National Forest Reservation Commission, up to June 30, 1927, a total of $14,065,260.87 in the purchase of 2,892,721 acres of forest land for the protection of navigable streams. These lands lie in the White, Allegheny, Appalachian, Ozark, and Ouachita Mountains. They are in 19 purchase units located in 13 States.

In the application of the protection-forest principle the Forest Service has proceeded upon the theory that, under our form of government, the duty and responsibility of establishing public forests and regulating their use should rest first upon that public agency

nearest to the problem, provided that agency is directly concerned in its solution, whether city, county, State, or Nation. The Federal Government should not step in if the local governing authority nearer the problem is willing and able to meet the public need. The same principle naturally applies all the way down the line. A town organization would not give an individual protection which he is able to provide by labor with his own hands on his own lands.

This principle has been kept in mind in this study. On Figure 6 are outlined many areas which are in urgent need of being given the status of public-protection forests, also areas within which it is known that there are lands which should be given such status. No attempt has been made at this time to determine the respective fields of local, State, and Federal activities in providing protection forests. As a principle of government, it is considered desirable from a national standpoint for cities, counties, and States to shoulder this responsibility so far as they are able to do so without undue hardship. Along with this principle, it has also been necessary to give due consideration to the fact that often the community nearest a protection forest is not so vitally concerned as others farther removed. In such cases it would be unreasonable and unjust to expect the local taxpayer to finance an activity for the primary purpose of benefiting other regions. In some cases Federal help seems to be the only reasonable solution because of large areas and heavy expense. In such cases, where the State has already signified its approval of Federal participation, prompt action by the Federal Government is recommended.

FORESTS OF THE MISSISSIPPI VALLEY

The forest area of the Mississippi Valley has undergone great changes since the advent of the white man.[2] His form of civilization has made tremendous inroads into the virgin stands which greeted the arrival of our pioneer ancestors. The first great inroad was made in the clearing of lands for cultivation in the Ohio River drainage. This activity swept through the valleys of the Ohio and its tributaries, spread out over the rich rolling uplands, and emerged on the still more inviting prairies of the North and West. So strong is habit that the rolling, timbered hills of Missouri were cleared and cropped before the prairie lands of Iowa were generally brought under cultivation.

The second great drain on the virgin-forest resources of the Mississippi Basin was lumbering. This started in rafting and floating logs and other forest products down the river to New Orleans for local and foreign trade, but got its greatest impetus when the pine, spruce, and hemlock forests of Wisconsin and Minnesota were drawn upon for the settlement and development of the great interior prairie of the Middle West. Like the clearing for agriculture, lumbering spread by widening circles into every region accessible to the growing country's demand. It reached into the great hardwood regions south of the Ohio River and sought new fields in Missouri, Arkansas, eastern Texas, Louisiana, and western Mississippi.

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[2] Evidences of these changes may be seen by comparing figs. 4 and 5.

The process of lumbering necessary in itself as an incident to settlement, growth, and industrial development, has unfortunately been almost universally followed, if not actually accompanied, by the forest's worst enemy, fire. This has not only taken a toll in timber probably equal in volume to that removed either in lumbering or agricultural clearings, but has in addition still more vitally affected the protective value of the forests and the future timber supplies by injury to the site, impoverishment of the soil, destruction of young growth, and the prevention of forest regeneration. Even in regions where these injurious effects are most evident, forest fires are still frequently considered an incident natural to the woods.

Considered entirely as a virgin area, the Mississippi Valley, even before the coming of the white man, was never what could be classified as a well-forested watershed. Not more than 40 per cent, or about 500,000 square miles, out of a total of 1,231,492 square miles, was in forests or woodlands at the time of discovery and settlement. (Fig. 4.) The fact that floods were characteristic of the Mississippi River from time immemorial need not disturb the champion of forests as a factor tending to regulate stream flow. If that fact has any significance it is evidence tending to associate floods with a nonforested area, since even in DeSoto's time floods occurred and 60 per cent of the watershed was then without forest cover. The primary cause of that flood, as well as the flood of 1927, was unusually heavy rainfall, the effect of which the 40 per cent of forest in DeSoto's time and the 20 per cent of forest in our own day might somewhat ameliorate but could not prevent.

Now only 20 per cent of the basin is in forests of any kind. Even this includes a considerable acreage of denuded land and for the most part is in an unsatisfactory condition as to forest cover and forest floor. (Fig. 5.) Only a small percentage of the land in forest is in satisfactory condition for timber production or watershed protection.

Table 2 shows for each of the six major basins of the Mississippi Valley the total area, the area originally in forest, and the present forest area including farm wood lots and nonrestocking forest land, with area comparisons in percentages. The last column gives for each basin the percentage of total area deforested. The "Total" line gives the same information for the Mississippi drainage as a whole.

TABLE 2.—*Forest lands of the Mississippi drainage*

Basin	Total area	Forest land (including wood lots and idle lands)		Percentage of basin areas		
		Original	Present	Original	Present	Decrease
	Square miles	*Square miles*	*Square miles*	*Per cent*	*Per cent*	*Per cent*
Ohio	203,782	186,000	68,000	91	33	58
Upper Mississippi	186,853	108,000	52,000	58	28	30
Lower Mississippi	52,688	51,000	29,000	97	55	42
Missouri	511,636	49,000	31,000	10	6	4
Arkansas-White	188,342	59,000	35,000	31	19	12
Red-Ouachita	88,191	44,000	29,000	50	33	17
Total	1,231,492	497,000	244,000	40	20	20

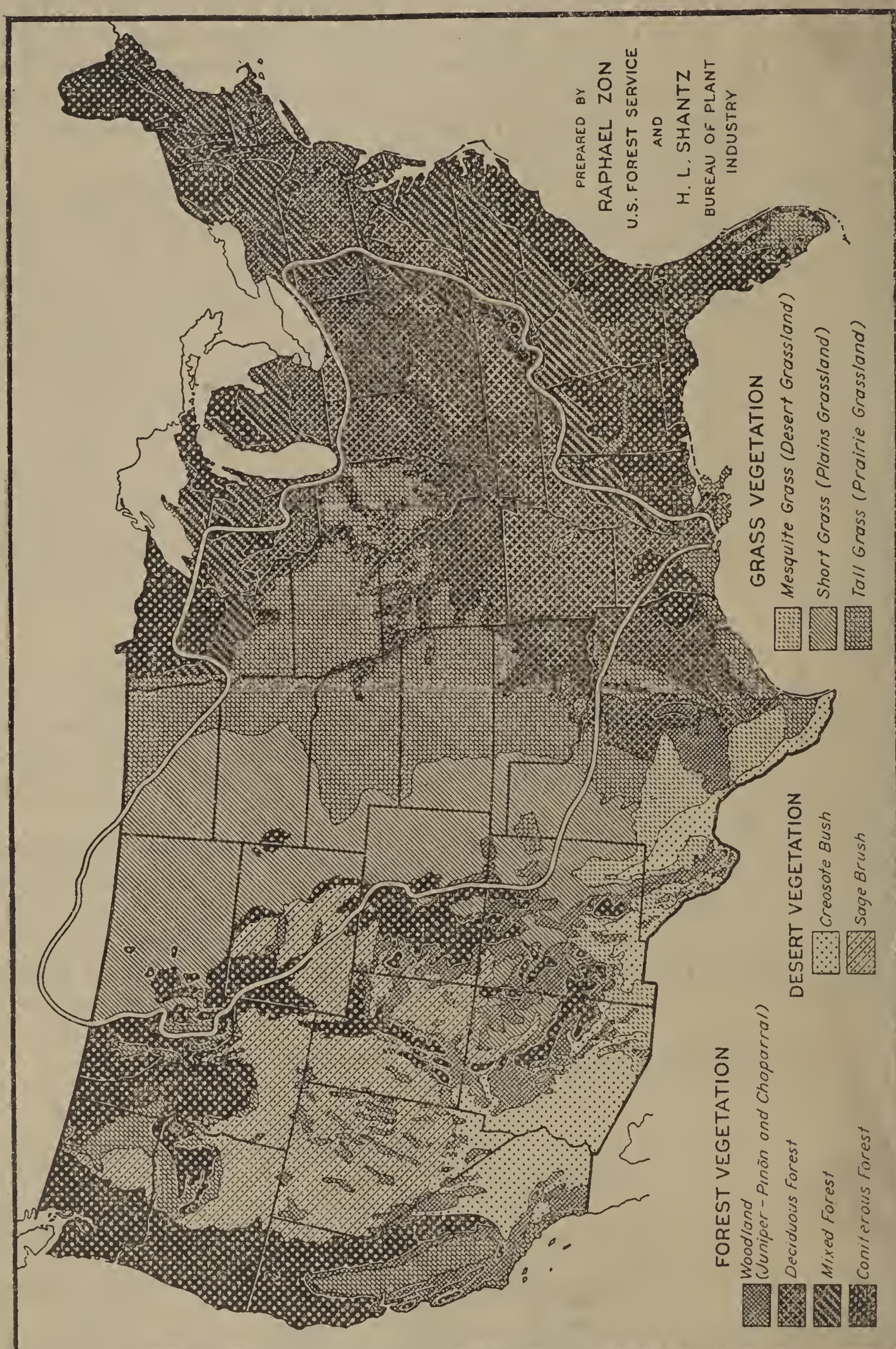
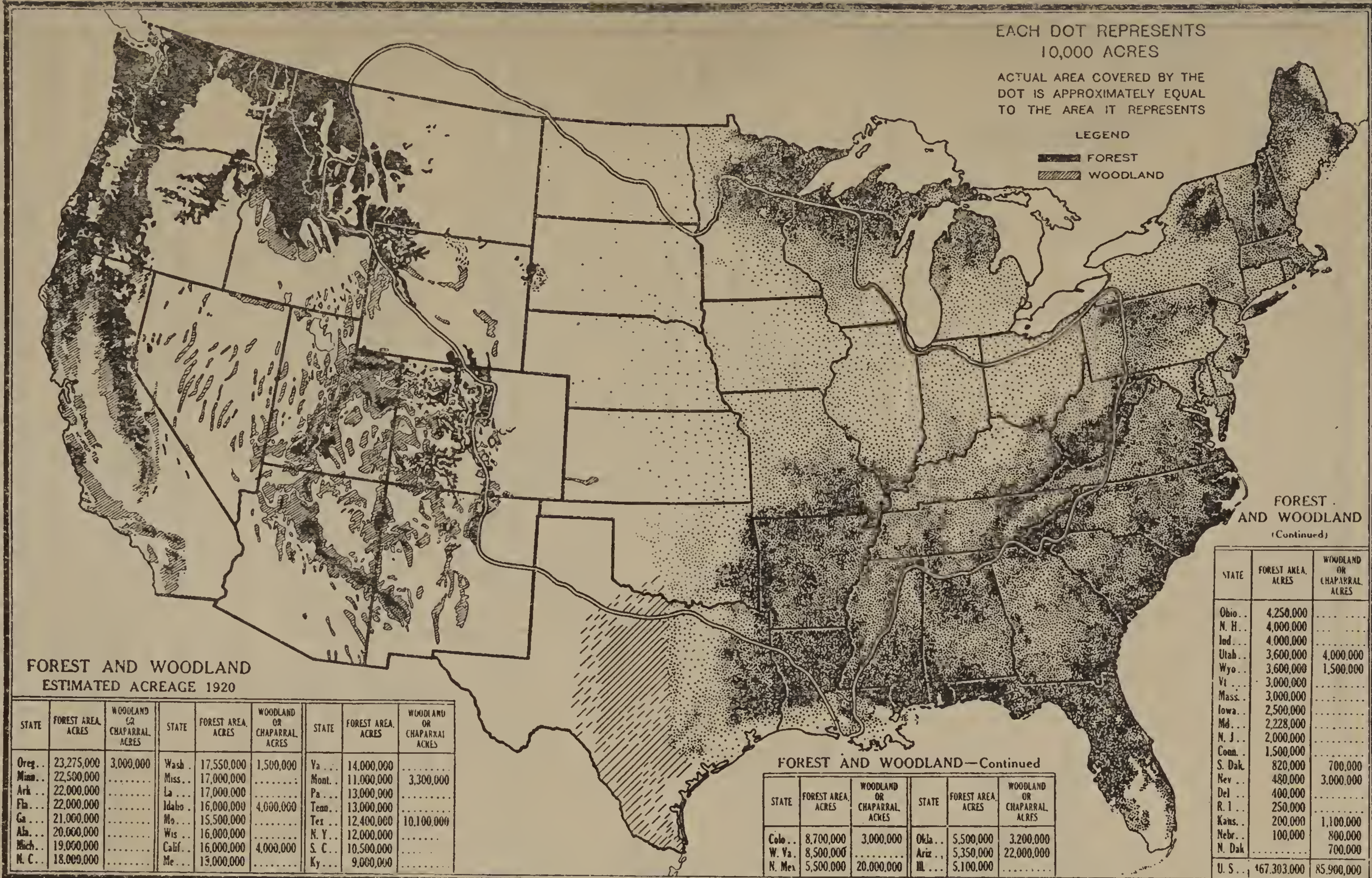


FIGURE 4.—Natural vegetation



FOREST AND WOODLAND
ESTIMATED ACREAGE 1920

STATE	FOREST AREA, ACRES	WOODLAND OR CHAPARRAL, ACRES
Oreg. .	23,275,000	3,000,000
Minn. .	22,500,000	....
Ark . .	22,000,000	....
Fla. . .	22,000,000	....
Ga . . .	21,000,000	....
Ala. . .	20,000,000	....
Mich. .	19,000,000	....
N. C. .	18,000,000	....
Wash .	17,550,000	1,500,000
Miss . .	17,000,000	....
La . . .	17,000,000	....
Idaho .	16,000,000	4,000,000
Mo . . .	15,500,000	....
Wis . .	16,000,000	....
Calif. .	16,000,000	4,000,000
Me . . .	13,000,000	....
Va . . .	14,000,000	....
Mont. .	11,000,000	3,300,000
Pa . . .	13,000,000	....
Tenn. .	13,000,000	....
Tex . .	12,400,000	10,100,000
N. Y. .	12,000,000	....
S. C. .	10,500,000	....
Ky . . .	9,000,000	....

FOREST AND WOODLAND—Continued

STATE	FOREST AREA, ACRES	WOODLAND OR CHAPARRAL, ACRES
Colo . .	8,700,000	3,000,000
W. Va.	8,500,000	....
N. Mex	5,500,000	20,000,000
Okla . .	5,500,000	3,200,000
Ariz . .	5,350,000	22,000,000
Ill . . .	5,100,000	....

FOREST AND WOODLAND
(Continued)

STATE	FOREST AREA, ACRES	WOODLAND OR CHAPARRAL, ACRES
Ohio . .	4,250,000	....
N. H. .	4,000,000	....
Ind . .	4,000,000	....
Utah . .	3,600,000	4,000,000
Wyo . .	3,600,000	1,500,000
Vt . . .	3,000,000	....
Mass. .	3,000,000	....
Iowa . .	2,500,000	....
Md . . .	2,228,000	....
N. J . .	2,000,000	....
Conn. .	1,500,000	....
S. Dak.	820,000	700,000
Nev . .	480,000	3,000,000
Del . .	400,000	....
R. I . .	250,000	....
Kans. .	200,000	1,100,000
Nebr. .	100,000	800,000
N. Dak	....	700,000
U. S. .	467,303,000	85,900,000

FIGURE 5.—Forest-land density

Table 3 gives the progress of forest destruction by basins. It shows the number of square miles of original forest cleared and devoted to farm pasture or other uses and the percentage of the original forest area of the basin which this area represents:

TABLE 3.—*Reduction of original forest lands*

Basin	Reductions	
	Area	Percentage of original forest
	Square miles	*Per cent*
Ohio	118,000	63
Upper Mississippi	56,000	52
Lower Mississippi	22,000	43
Missouri	18,000	37
Arkansas-White	24,000	41
Red-Ouachita	15,000	34
Total	253,000	51

The estimate of a total of 244,000 square miles of forest lands in the Mississippi Basin includes not only the commercial forests, farm woodlands, and other timberlands, but also includes about 35,000 square miles of so-called "idle" or "waste" lands. These are areas once timbered or adapted to timber growing which have been so denuded by overcutting and repeated fires that they are no longer capable of restocking themselves with valuable timber in commercial quantities. Hence they are of such low value that no one will make an effort to protect them. Lacking timber cover and continually robbed by fire of surface protection, they offer only low resistance to erosion.

About 10,000 square miles of such "idle" or "waste" land is included within the total of 115,000 square miles of woodlands belonging in farm ownership. The farm woodlands are chiefly in regions devoted primarily to agriculture.

The 129,000 square miles of forest land not in farm wood lots are in the regions where soil and topography generally are more favorable for forest growth than for farm use. Unfortunately, only about 104,000 square miles are occupied by tree growth of commercial species, 25,000 square miles falling in the "idle" or "waste" class.

HOW THE WATERSHED FORESTS WERE STUDIED

It was to the 244,000 square miles of forest lands remaining on the Mississippi watershed, some timbered and some idle or waste, scattered through the 6 major basins and 73 individual drainage units, that this study was directed. It is desirable to make clear at this point that the value of a forest in preventing erosion and regulating stream flow is not directly proportional to the volume of timber on any given area. It is influenced by other factors, such as density of cover, amount and character of undergrowth, and depth of humus accumu-

lation. A mature forest in open stand may support a large amount of merchantable saw timber and yet, because of overgrazing or repeated ground fires, be so devoid of undergrowth and leaf litter as to be rated very low from a protection standpoint. On the other hand, a watershed may be very well protected by a young or scrubby growth or by thickets of inferior species by reason of the density of its canopy and the depth of litter accumulation.

Previous general studies of the forests of different regions of the United States have been made principally for the purpose of determining the value of the forests as sources of lumber or other wood products or of estimating their timber-producing possibilities. But the flood problem required a study of forest areas markedly differing from anything ever before undertaken on so large a scale. The primary purpose was to find out, if possible, to what extent our forests may be relied upon to help reduce floods and flood damage on the Mississippi.

This required at the very outset a study of the forests and forest lands of the basin to determine the extent and location of areas having important protective significance as distinguished from areas from which run-off was not materially influenced by the presence or absence of forest cover.

CRITICAL AREAS [3]

In the plan of this study an endeavor was made first to localize the source of the watershed trouble so far as was found practicable, in order that effort might not be wasted, and that attention might be focused on the "critical areas" rather than diverted to others of less importance.

To be of any substantial or permanent value, it was evident that the classification of the areas could not be based entirely upon the immediate efficiency of each watershed. It was obviously just as important in the long run to prevent a good-protection forest from being injured as to restore the efficiency of a similar area which had already been injured. Just as important and much cheaper and easier.

There was therefore placed in the "critical areas" class all forest lands found to be of such character, by reason of factors of soil, slope, and precipitation, that to prevent flashy run-off or destructive erosion the maintenance of a good forest cover was necessary as proved by the results of forest destruction on similar land. It was upon the areas so classified as "critical areas" that this study finally centered. Under this general designation of "critical areas" two general regions not falling in the class of forest lands were finally included. These are the Bad Lands and the Breaks.

How determined.—The determination of "critical areas" involved the consideration of many complex and conflicting factors. While the three main factors which determined the final classification (soil characteristics, physiography, and precipitation) are relatively con-

[3] See fig. 6 and Table 7.

stant for each part of a drainage unit, they vary for different parts of the unit. Furthermore, each factor is exceedingly complex. For example, an average precipitation of 40 inches annually in the form of an occasional torrential rain will have a very different effect from the same total amount of precipitation in many gentle rains well distributed throughout the year. Any system of measurement based upon factors so variable is obviously not infallible. At the same time it has furnished the Forest Service with a substantial background of information which, when checked by run-off conditions on the ground, is reasonably accurate. At least it gives different examiners in different regions common standards of measurement and

FIGURE 6.—Critical erosion areas

make comparisons possible. Faulty as this method may be, wide diversity of conditions required the adoption of some uniform method of rating watersheds in order to make possible the summations and comparisons absolutely essential to any real conception of actual conditions on such a large area.

By means of the rating system adopted Figure 6 now gives for the first time a graphic presentation of the areas where the maintenance of good forest cover is believed to have an important relationship to flood control.

The location of "critical areas" having been determined, a further classification was made according to present conditions. Those which were not the source of heavy deposits of silt or flashy run-off were

classified as "beneficial." Those which had seriously deteriorated but were apparently in a static condition, if not actually improving, were classified as "neutral." Where deterioration was active the areas were classified as "detrimental."

HAS DEFORESTATION INCREASED THE SEVERITY OF MISSISSIPPI FLOODS

It has not been possible within the limited time available for this study to determine quantitatively to what extent forest depletion has contributed to the Mississippi floods. It has seemed more important to determine how and to what extent forests may contribute to flood prevention. It is sometimes claimed that there has been no marked change in the Mississippi flood situation due to deforestation or any other cause. This study has not undertaken either to prove or disprove such a theory. It does, however, seem well to call attention to certain facts: (1) By the construction of dams at the outlets of certain lakes, Lake Winnibigashish and others, reservoirs have been established at the headwaters of the Mississippi constituting what is said to be the greatest water-impounding system in the world. (2) There is now under irrigation in the Mississippi Valley, according to the 1920 census, a total of 5,005,577 acres of arid land.

The impounding capacity of the lake reservoirs at the headwaters of the Mississippi is reported to be slightly in excess of 95,000,000,000 cubic feet. A reasonable estimate of the average amount of water used in irrigating arid lands on the Mississippi watershed in 24 inches annually. The total amount of water diverted from stream flow and absorbed by the reported acreage of irrigated land each year is therefore more than 435,000,000,000 cubic feet, or more than four and a half times the total capacity of the great reservoir system in Minnesota. Of course, not all of this water is consumed by evaporation and plant growth. A considerable part eventually reappears in springs elsewhere and returns to stream flow, but such return is a gradual process. These are only two outstanding examples of the control of water in the Mississippi Valley out of hundreds that have taken place during the past 40 years. If, therefore, there has not been a marked change in the flow of the river during this period the only possible explanation seems to be that such works beneficial to the stability of stream flow have been offset by other factors of equal power, but working in a detrimental direction.

STUDY REQUIRED CONSIDERATION OF ALTERNATIVE USES OF FOREST LAND

The study of the protective influence of forests in the Mississippi Valley and of the contribution that effective forest protection, necessary reforestation, and the productive use of land for forest crops, may make to flood control, proved to the men engaged in this work that, broadly speaking, the problem was one of the wise use of land. It was found necessary not only to study the areas which are in forests and to determine whether or not they were doing their share toward water and soil conservation, but in many cases it seemed even

more necessary to study lands which, although not now in forests, should be.

It may as well be stated at this time that undoubtedly the greatest burden of silt and freshet run-off contributed to the Mississippi River comes not from forest land, but from farm lands which are being unwisely used. The reports on the 6 major basins and the individual reports on the 73 drainage units uniformly testify to the general fact. Not only are the silt and run-off greater from the agricultural regions as a whole than from the forest regions—it could hardly be otherwise from a great basin only 20 per cent in area timbered—but greater in proportion to area.

Again it should be made clear that it is not the original lumbering operations which have mainly caused soil impoverishment, erosion, and floods, but the repeated fires which have usually followed such operations. Nature is a great physician. If given a reasonable opportunity, she displays marvelous skill and promptness in curing many ailments. The forest on a hillside may be removed by fire or logging operations. The first year following such destruction or utilization the snowfall goes off in a torrential rush, which makes a gully of every road, log slide or wheel track. But in a few years, at the most 5 or 6 in relatively humid regions or 15 or 20 in semiarid regions, if there have not been repeated fires, nature will have stopped destructive erosion. But, unfortunately, the curative process of nature is usually defeated by the destructive process of burning the woods. Erosion may be stopped in a few years, but it takes much longer to rebuild the mat of humus to its maximum storage capacity and restore the diminished springs to their original flow. The odds against nature are usually so great that such results can not be expected without effective fire protection and intelligent forest management.

CLASSIFICATION OF FORESTS

For purposes of this circular, the forest lands of the Mississippi Valley have been divided into three classes based directly on ownership—but ownership largely as influenced by use. The three classes are as follows:

1. Commercial forests privately owned.
2. Farm woodlands and forest lands within regions where agricultural interests are generally dominant.
3. National forests and national parks and the unreserved timbered portions of the public domain.

COMMERCIAL FORESTS

Lands classed as commercial forests, which in some regions are often given the general designation "lumber woods," embrace the major lumber regions of the valley and have in the aggregate a total area of 108,000 square miles, including cut-over and waste lands similar in character and location. They are in private or corporate ownership and are the source of most of the lumber produced in

the valley. Generally speaking, they are of negligible value for farm-crop production chiefly because of soil or topographic features. They are broadly grouped under the following subdivisions:

1. "Lumber woods" of Minnesota and Wisconsin;
2. Hardwood region of Ohio Basin;
3. Bottom-land hardwoods of Mississippi Delta;
4. Southern pine region of Louisiana, Mississippi, and Arkansas, with adjoining upland hardwoods.

Each of the foregoing regions will be discussed separately. One important feature common to all is the fire hazard and the injury which has resulted from the ravages of fire. Each region has its season of fire danger. In each region fire control is a major factor in forest perpetuation. Yet in each region this fact has been given little consideration by the landowner until recently unless merchantable stands of saw timber, improvements, equipment, or saw logs have been threatened.

Section 2 of the Weeks law of March 1, 1911, recognized the importance of forests from a stream-protection standpoint and authorized Federal cooperation with the States in protecting from fire the forested watersheds of navigable streams. This encouraged States and private owners in many regions to undertake systematic fire protection. The Clarke-McNary law broadened the basic act, with the result that the Federal Government is now cooperating in organized fire protection with 20 States lying wholly or partly within the Mississippi Valley.

The Clarke-McNary law was based upon the theory that fair division of the costs of protecting forest lands from destruction was 50–50 as between the private owner and the public; that one-half of the public share should be assumed by the Federal Government and one-half by the local powers, and that the work should be directed by State authority.

Under this law progress is being made in protecting the forests of the Mississippi Valley as well as elsewhere, but not as rapidly as could be wished.

On Figure 7, the area in the Mississippi watershed now covered by cooperative fire protection is shown graphically. By comparing this with Figure 6, showing the areas which are critical from a flood standpoint, it will be seen that the blanket of protection falls far short of covering the areas of fire hazard. However, the trouble lies not so much in the shortness of the protection blanket as in its thinness. The organization is far from being adequate to cope with the danger. This situation is shown in detail by Table 4, which gives for each State the area in the Mississippi drainage requiring forest protection, the estimated cost of adequate protection and the extent to which the Federal Government is meeting its 25 per cent of such

estimated cost, also the extent to which the private owners and States are meeting their 75 per cent of the estimated cost of adequate protection.

TABLE 4.—*Fire-control cooperation, under section 2 of Clarke-McNary law, with States and private owners in the Mississippi Valley*[1]

State	Approximate area of State and private forest land in need of protection	Estimated cost of protection	Federal share of cost 25 per cent of whole	Federal funds available fiscal year 1928	Extent to which Federal Government is meeting responsibility	State funds available fiscal year 1928	State share of cost 75 per cent of whole	Extent to which States are meeting responsibility
	Acres				*Per cent*			*Per cent*
Alabama	2, 000, 000	$23, 140	$5, 785	$1, 968	34. 0	$2, 282	$17, 355	13. 1
Georgia	341, 400	5, 500	1, 375	430	31. 3	593	4, 125	14. 4
Kentucky	9, 000, 000	225, 000	56, 250	14, 404	25. 6	14, 404	168. 750	8. 5
Louisiana	8, 510, 000	203, 700	50, 925	19, 400	38. 1	57, 036	152, 775	37. 3
Maryland	50, 000	2, 856	714	280	39. 2	1, 400	2, 142	65. 4
Minnesota	9, 000, 000	132, 980	33, 245	21, 715	65. 3	102. 059	99, 735	102. 3
Mississippi	4, 000, 000	90, 000	22, 500	7, 910	35. 2	13, 760	67, 500	20. 4
Missouri	10, 000, 000	260, 000	65, 000	11, 000	16. 9	11, 000	195, 000	5. 6
Montana	1, 000, 000	17, 680	4, 420	1, 685	38. 1	5, 150	13, 260	38. 8
New York	400, 000	27, 000	6, 750	2, 890	42. 8	14, 855	20, 250	73. 4
North Carolina	600, 000	16, 000	4, 000	1, 368	34. 2	1, 700	12, 000	14. 2
Ohio	1, 100, 000	27, 800	6, 950	2, 913	41. 9	14, 623	20, 850	70. 1
Oklahoma	5, 000, 000	160, 000	40, 000	13, 710	34. 3	14, 670	120, 000	12. 2
Pennsylvania	3, 600, 000	104, 960	26, 240	10, 035	38. 2	58, 100	78, 720	73. 8
South Dakota	50, 000	1, 500	375	375	100. 0	7, 235	1, 125	643. 1
Tennessee	10, 000, 000	250, 000	62, 500	21, 250	34. 0	21, 250	187, 500	11. 3
Texas	300, 000	5, 588	1, 397	477	34. 1	496	4, 191	11. 8
Virginia	1, 000, 000	30, 072	7, 518	2, 560	34. 0	2, 560	22, 554	11. 4
West Virginia	5, 850, 000	140, 500	35, 125	13, 290	37. 8	44, 388	105, 375	42. 1
Wisconsin	12, 000, 000	232, 400	58, 100	23, 100	39. 8	86, 856	174, 300	49. 8
Total	83, 801, 400	1, 956, 676	489, 169	170, 760	34. 9	474, 417	1, 467, 507	32. 3

[1] Total funds available, fiscal year 1928, $645,177; additional sum required to provide adequate protection, $1,311,499 a year, of which the United States Government should provide an additional $318,409, and the private owners and States should provide an additional $993,090.

It will be seen from Table 4 that at the present time the protection given the forests of the Mississippi Valley is about one-third adequate. Obviously, we can not expect these forests to give satisfactory protection from erosion to the critical areas and from flood to the lowlands unless the forests themselves are adequately protected. After the study which Congress has already given this part of the forest problem, it does not appear necessary to extend the discussion in this circular further than to say that the reports on each individual drainage unit constituting the great basin of the Mississippi indicate that forest fires everywhere play a large part in forest depletion. Even where the standing timber is not consumed or killed, repeated fires are preventing the accumulation of normal undergrowth, small trees, and depth of humus. Fires are in every region reducing the storage capacity of the privately owned commercial forests; and freshet run-off accompanied by unnecessary erosion results. No matter what other steps are proposed, effective fire control is needed in all the forest regions on the Mississippi watershed. It is the first step in developing the possibilities of forests for flood prevention.

LUMBER WOODS OF MINNESOTA AND OTHER LAKE STATES

The lumber woods of Minnesota and the other Lake States is a region of conifers or mixed conifers and northern hardwoods, such as beech, birch, and maple. Its southern boundary runs from east and west as follows: From Kilburn northwest to Black River Falls, thence to Eau Claire and St. Croix Falls, Wis., or Taylors Falls, Minn., thence west to Rush City, thence to Milaca, thence to Little Falls and Wadena, and thence north to Itasca Lake.

This was the region of the great northern white pine and Norway pine forests on the sandy plains. The swamps contained black spruce, northern white cedar, tamarack, and balsam fir. Only a negligible amount of virgin forest remains. Fortunately the watershed problem in this region is not generally critical. Much of the area has sandy soil which, in this comparatively level country, absorbs precipitation promptly and is not subject to erosion. In addition, swamps and innumerable lakes combine to make the whole region a natural storage reservoir. This has been supplemented by a system of six great reservoirs constructed and operated by the United States Engineer Corps. The total capacity of this system, which embraces Lakes Winnebigoshish, Leech, Pokegama, Pine, Sandy, and Gull, is 95,268,100,000 cubic feet.

Despite the fact that these lands are in an exceedingly unsatisfactory condition from the standpoint of timber production, they are not generally a menace to the watershed. The condition of the soil, the topography, and the numerous lakes which act as storage reservoirs and settling basins all combine to furnish a very regular flow of water unusually free from sediment. This statement can be made for the Mississippi River as a whole as far south as the outlet of Lake Pepin, which acts as its last general settling basin.

One exception is noted at the head of the Wisconsin River, where, owing to the character of topography, nature of soils, and climate, the preservation of forest cover is of public importance. An examination of this general region has been made by the secretary of the National Forest Reservation Commission in furtherance of the Weeks law, and an area of about 250,000 acres of rough land with innumerable lakes has been found to have great possibilities as a protection forest under public ownership or control. About 100,000 acres of the area lie on the Mississippi drainage and could probably be acquired at an average price of about $2.50 per acre. This area appears to be the one portion of the lumber-woods region of the Lake States the control of which for forestry purposes would have any material bearing on the flood situation.

It may and undoubtedly will be necessary to establish other public forests in this part of the Mississppi Valley for fire-control and wood-production purposes, since a great extent of excellent forest land is needlessly lying waste. This may involve the problem of managing swamp lands for forest and game purposes, or may, for example, provide for the enlargement of the present Minnesota National Forest. Such lands, important as their proper use may be from the

viewpoint of conserving economic resources, do not appear to have sufficient bearing upon flood control to warrant consideration in this study.[4]

BOTTOM-LAND HARDWOODS

With the exception of the area of sandy plains and innumerable lakes of the "lumber woods" region of the Lake States, no other considerable body of forest land in the Mississippi Valley presents

[4] Data made available in the report of Nov. 28, 1927, issued by the Mississippi River Commission since the foregoing paragraph was written, seem to indicate that the presence and character of forests even in this region have a much greater influence on run-off than is usually supposed. The report states that below Pokegama Lake, near the headwaters of the Mississippi River and just above Grand Rapids, Minn., a reservoir dam was built across the Mississippi River more than 40 years ago (1884). The run-off from the entire watershed above that point is collected in this and two other reservoirs in the same basin. Aside from evaporation, and allowing for change in the amount of stored water, the entire run-off of this watershed has passed through Pokegama Dam. Its discharge has been measured accurately for 42 years and checked from the discharges of the two reservoirs above; the rainfall has been measured daily at the three dams for the same period, and the area of the watershed has been carefully determined as 3,265 square miles. Of this area 584 square miles are lake surface and 2,681 square miles are land surface. The report of the Mississippi River Commission (p. 74) says:

"The region is one where normal rainfall and normal evaporation are about equal. Therefore the rainfall over the lake surface is lost by evaporation and the measured run-off is that of the 2,681 square miles of land. Thus we have with great accuracy the three features necessary to a complete determination of the relation of run-off to rainfall—area of watershed, rainfall, and run-off. In the 42 years mentioned the basin has passed through all phases, from virgin forest, through the logging period, and forward to agriculture or backward to a growth of scrub and young timber—autoforestation. Due to the fact that much of this area is Indian reservation, and most of it poor agricultural land, it has largely gone backward rather than forward."

The report of the Mississippi River Commission furnishes the gist of the 42 years' observations, divided into six 7-year periods, in the form of a table which is given below, supplemented by a final column furnished by the author of this circular showing the number of inches of rainfall retained by the watershed and the number of inches of run-off:

7-year periods	Average annual rainfall		Run-off	Run-off in percentage of rainfall	Water	
					Run-off	Retained
	Inches	*Million cubic feet*	*Million cubic feet*	*Per cent*	*Inches*	*Inches*
1885 to 1891	25.318	1,103,856	222,745	20.18	5.108	20.21
1892 to 1898	26.417	1,151,774	261,460	22.70	5.997	20.42
1899 to 1905	29.687	1,294,967	442,545	34.17	10.147	19.54
1906 to 1912	24.446	1,066,379	252,565	23.68	5.786	18.66
1913 to 1919	25.420	1,108,292	284,002	25.63	6.510	18.90
1920 to 1926	21.583	941,078	148,933	15.83	3.413	18.17

The first three periods cover the time from virgin forest to practically complete deforestation, as far as pine timber, the principal native growth, is concerned, and the last three periods cover a gradual relapse to scrub with the growth of young timber (autoforestation), and some advancement to farms. It will be seen from the above figures that the percentage of run-off increased as deforestation advanced and decreased again as a growth of scrub and young timber gained foothold. More marked, however, is the influence of the forest shown by the figures in the last column, which indicate the number of inches of rainfall actually retained by the land. The average for the first two 7-year periods, which included the virgin-timber epoch, is 1.775 inches a year greater than the average for the last two 7-year periods. An absolute reduction in run-off of this amount applied to a large area would obviously have tremendous influence upon the action of the streams affected. In this particular case, however, the increase in run-off during the period of deforestation and the reduction in run-off as the forest is restored may be accounted for by a marked increase in average precipitation during the first epoch and a marked decrease during the last. The Mississippi River Commission, misunderstanding the theory of the application of the forest to the regulation of stream flow, compared these data with similar data from another watershed which was farmed extensively, and reached the conclusion "that farm lands reduce run-off more than do cut-over lands," a conclusion which is absolutely sound but is of little more than academic interest, since lands valuable for farming are not usually considered for forest purposes. The further conclusion of the commission "that cut-over lands have no greater run-off than do virgin forests" is a misinterpretation of the forest-protective influence shown by the above table, since the proper measure of effectiveness in a given condition is the number of inches of water actually retained by the watershed rather than the percentage of run-off.

so simple a problem from a flood-control standpoint as the timbered bottom lands of the Mississippi Delta.

This type of forest, from Cape Girardeau to the Gulf, can be said generally to be the forest type originally common to the lands now subject to overflow or in danger of inundation by floods. Such forests are of service in binding the soil along the stream banks and in checking destructive washing. They can not be said to increase or lessen flood volume materially, although they consume a great amount of moisture in the process of growth and thereby produce valuable material on lands which in an undrained condition were otherwise unproductive. Forests may even be undesirable when they occupy portions of the flood plain where the distance between the levees is narrow and rapidity of current is desirable, since they tend to retard stream flow. On the other hand, bottom-land forests may be the best crop to raise on overflow lands where there is room for the stream to spread out. Since the forests tend to retard the flow, this aids the water to deposit its excess load of silt, thereby reducing its power to do damage as it travels on down the river.

The Delta hardwoods grow with unusual rapidity owing to the rich soil, heavy rainfall, and long growing season. Where the soils are properly drained and are assured protection from overflow such lands are of course too valuable to devote to forests. However, where the lands are poorly drained or where overflow is periodic and particularly where the soil may be endangered either by being washed away or buried in a covering of river sand, trees may prove to be the most valuable crop. If, therefore, it should be found necessary for the public to acquire bottom lands for overflow or reservoir purposes, consideration should be given to their utilization as public forests, whereby their earning powers for wood production would be used as a means of lightening the burden placed upon the public by flood-prevention expenditures.

Above the Delta, the bottom-land hardwood type continues to a considerable distance. However, in its northern extension it is chiefly stream marginal in character and falls in the general classification of farm woodlands. The necessity of exercising care in the management of such lands will be discussed in dealing with forest lands of that class.

UPLAND HARDWOODS OF OHIO RIVER BASIN

The entire Ohio River drainage, with the exception of about 17,000 square miles of prairie lands in Indiana and Illinois, was originally practically one vast forest, largely of hardwoods. There were limited amounts of northern white pine and hemlock in the upper Allegheny region in Pennsylvania and New York, and minor tracts in Ohio. Only a few remnants of these conifers are left. There were also limited forests of spruce and hemlock in the mountainous parts of West Virginia, North Carolina, and Tennessee, some of which continue unchanged as to type, although largely cut over.

In no other drainage basin of the Mississippi has human occupancy changed forest conditions to so great an extent as in the Ohio Basin. Of a total area of 203,782 square miles, of which 186,000 square miles was timbered, only about 68,000 square miles of forest or forest land remains. This is broadly described as falling into two classes:

(1) Comparatively contiguous bodies of timber in the mountainous and plateau regions; (2) farm wood lots, which are isolated small bodies of timber scattered through the better agricultural sections, and fringes of hardwood species generally found on the bluffs and banks of stream courses bordering agricultural lands.

The plateau and mountain forests are the only areas in the Ohio Basin requiring special discussion, since the farm wood lot and stream marginal woods in the regions essentially agricultural will be considered as a general class for all major basins of the Mississippi.

Proper care of forest land is particularly desirable in this basin, because it has a very high run-off for its area as compared with the other major basins. There is a striking contrast between its estimated average run-off of 300,000 second-feet from 203,782 square miles and the 100,000 second-feet from 511,636 square miles in the Missouri River Basin.

By a glance at Figure 5, showing the distribution and density of forest lands in the Mississippi Valley, one sees that these plateau and mountain forests are two almost continuous bodies of land, largely in forest, practically paralleling one another but separated by the valley of the Tennessee River. The one lying to the south covers the most rugged parts of the southern portion of the Appalachian Mountains. The more extensive one to the north and east is known as the Cumberland Plateau through Kentucky and Tennessee and as the Allegheny Plateau in West Virginia and Pennsylvania. A remnant of this formation having a high percentage of forest land lies in western Tennessee just east of the river of that name and quite removed from the main portion of the plateau.

In the more southerly Appalachian Mountain region the plans of the Federal Government for forest protection and stream-flow regulation have already been well crystallized, as will be seen from Figure 8. Practically all of the region, containing more than 75 per cent of forest land, is already within the boundaries of national forests created from purchased areas established by the National Forest Reservation Commission under authority of the Weeks law, or in the Smoky Mountain National Park more recently authorized by Congress. The task of completing the actual purchase of the forest lands within these units remains. The same statement holds true for the several national forests on the Allegheny Plateau farther north, and for that part of the Alabama National Forest lying within the Ohio Basin.

There is still, however, a wide gap between plans and accomplishment as far as actual purchases of land in the national forests in the Ohio Basin are concerned. The total area within such forests is 3,931,476 acres, while the area of net Government land acquired is only about 700,000 acres. However, lands are steadily being offered for sale, and purchases are being made by the Government. These national forests will doubtless ultimately be carried to completion without receiving any further consideration from a flood-control standpoint.

The conditions which necessitated the establishment of public-protection forests in the main mountain range are found to exist in

equal degree over a considerable extent of the plateau lying north of the Tennessee River and terminating in the Allegheny National Forest in Pennsylvania. Within this region a number of areas have been examined by the Forest Service under the provisions of the Weeks law and found to meet the requirements of public-protection forests. These areas are shown in Figure 8, and are indicated by the numeral 3. The examiners' reports have shown that such areas are sadly in need of protection, but the funds at the disposal of the National Forest Reservation Commission have never seemed sufficient to justify a recommendation that the commission extend its program to this region. Another deterrent feature has been the fact that much of the area is underlain with coal, which necessitates limiting purchases to surface rights, with a mineral reservation and use running to the mining company. However, in other mineral regions it has been found practicable to meet this situation through a division of surface and subsurface rights, and there is every reason to feel confident this plan will prove workable here.

Three other units, shown in Figure 8 and indicated by the numeral 2, are roughly outlined areas which are reported as urgently in need of public protection-forest status. In addition, a considerable number of regions are outlined in Figure 8 and indicated by the numeral 1 within which there are areas of greater or less extent which are eroding badly and from which unnecessarily turbid and flashy run-off contributes to the general flood problem of the basin. The establishment of such areas as protection forests would be a contribution to regularity of stream flow. These regions are recommended for future consideration and examination with a view to determining the proper ultimate status of such lands.

SOUTHERN PINE REGIONS AND ADJOINING UPLAND HARDWOODS

The southern pine and adjoining upland types of forests are treated together as a single region, for the reason that they are found closely intermingled and allied. Their territory includes all land outside of the bottom-land hardwood type in Mississippi, Louisiana, Arkansas, the southeastern third of Oklahoma, the northeastern corner of Texas, most of the State of Missouri south of the Missouri River, and that part of Tennessee and Kentucky not drained by the Ohio. Pine predominates in the Mississippi region, south of the Black River in Louisiana, and in Arkansas south of the Arkansas River. Elsewhere west of the Mississippi the two types divide the territory about evenly. East of the Mississippi and north of Black River upland hardwoods prevail, these being in reality a continuation of the vast hardwood belt extending westward from the Ohio Basin.

While forest depletion is far advanced in this region there still remains a much larger acreage of virgin timber than in any other forested region of the United States east of the Rocky Mountains. Cutting for commercial lumbering and clearing for agriculture have advanced farther as a whole in the pine type than in hardwoods. Considered separately, commercial lumbering has made greatest inroads in the pine forests and clearing for agriculture has made greatest advances in the hardwood type. This is the natural result

of pine being most in demand for milling purposes and of the hardwood lands having generally richer soils than the pine lands.

Because of even topography and sandy soils, a considerable part of the pine land west of the Mississippi, like the sandy pine land of the Lake States, does not erode readily and quickly absorbs rainfall to the limit of the capacity of its soils. For this reason the presence of forest cover is not essential from the standpoint of stream-flow regulation. Consequently large parts of the forest lands as shown in Figure 5, although largely in an unsatisfactory state from the standpoint of timber production, are not shown as critical areas upon which the maintenance of good forest cover is essential to stream-

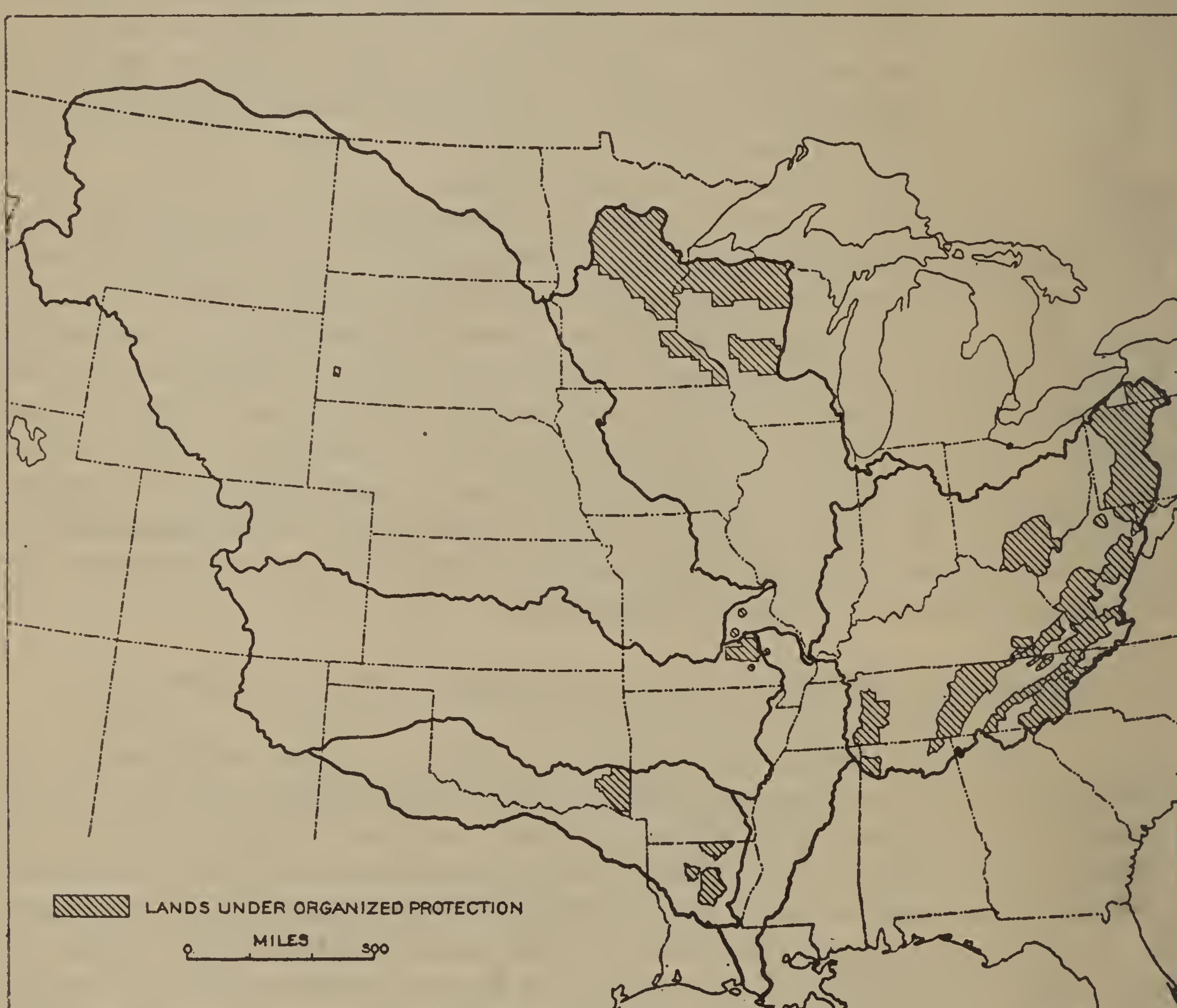


FIGURE 7.—Area protected against forest fire (under Clarke-McNary Law)

flow regulation. This statement holds good for a considerable part of the pine lands of Louisiana and Arkansas. However, several areas of comparatively rough or broken lands, with prevailing steep slopes are shown in Figure 6, which are exceptions to this rule. Upon these the maintenance of the forest is necessary to prevent erosion and freshet run-off. The same condition prevails on the areas of pine lands indicated as critical in Figure 6, in Arkansas, Oklahoma, and Missouri. The establishment of the Ouachita and Ozark National Forests in Arkansas has resulted in improved conditions in that portion of the State which embraces the rougher regions. However, the problem of fire protection has proved so difficult that even now these areas can not be rated better than neutral from a water-

shed standpoint. If protection from fire can be made effective these should eventually become beneficial. However, much still remains to be done before satisfactory fire control is realized. Public sentiment appears to be changing in favor of fire prevention, as against the long-standing practice of woods burning.

Lying east of the Mississippi and extending from southwestern Kentucky on the north through Tennessee, Mississippi, and Louisiana on the south, is a long, comparatively narrow area which as a flood menace and erosion problem appears to be by long odds the most serious and important of any in the Mississippi Valley. The white area adjoining it on the west, as shown in Figure 6, is bottom lands, The area shown as critical is high land. This is a region of exceed-

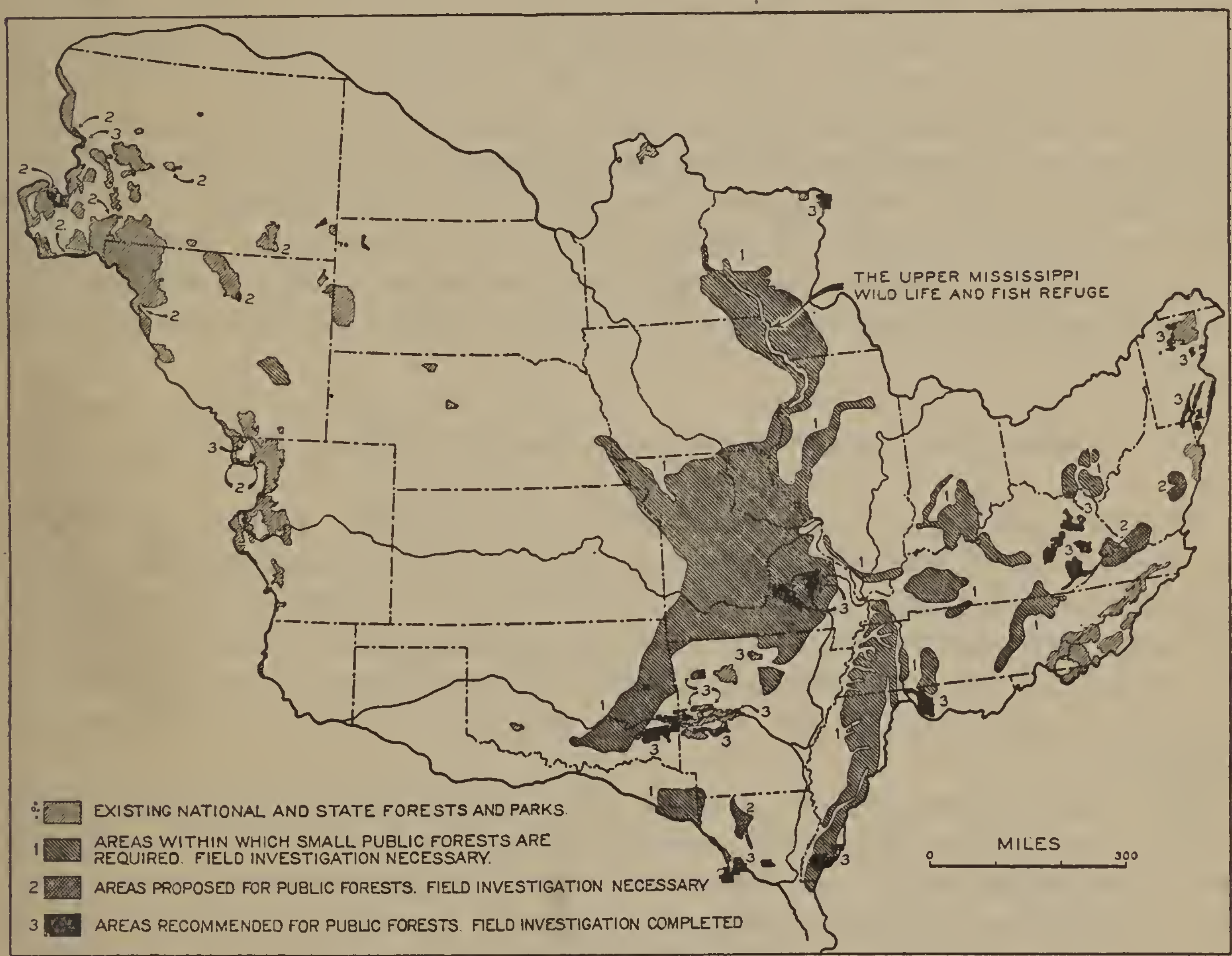


FIGURE 8.—Reservations: Existing and proposed

ingly deep and loose soils, subject to excessive erosion. These soils are of wind-blown origin, picked up from the river-borne silt through the endless ages and deposited by the prevailing winds from the west. The soils are deepest and conditions most critical, generally speaking, along the western rim and shade off gradually toward the east. Examples of vertical gully erosion 20, 40, and 60 feet deep are not uncommon. One case was reported with a depth of 160 feet. This conditions of deep, loose soils in a region of heavy rainfall requires a very slight slope to start destructive erosion. In one drainage unit (the Homochitto) the 1925 census shows a reduction of about 30 per cent in plowlands as compared with 1920, due largely to the enforced abandonment of eroded fields. Within this unit the secretary of the National Forest Reservation Commission has examined the two areas outlined, one of 218,000 acres and another of 420,000 acres, as shown in Figure

8, with a view to recommending purchase by the National Forest Reservation Commission. However, a portion of the eastern area is not essential to stream-flow regulation. The total of the two areas so classified is found to be 546,000 acres. The Mississippi enabling act at present limits forest-land purchases by the Federal Government to only 25,000 acres, and this should be given consideration in planning an immediate program of Federal purchases.

The urgent necessity of exercising care in handling the lands in this region of delicate balance can not be overestimated. It is important from a flood standpoint; it is important from a drainage standpoint, since the silt from these lands fills the drainage canals on the lowlands; not only is it important for the protection of the lowlands from silt and floods, but the protection of these lands is also vital to the future usefulness of the region itself. Destruction is now taking place that can never be remedied. Much of this destruction can be stopped, but it will require real effort to stop it. The entire area is therefore shown in Figure 6 as "detrimental" and recommended for examination with a view to determining what portions are so subject to erosion that they should be permanently kept in public forests for protection purposes. These will be the steeper, rougher lands along the western border of this general soil type.

PROTECTION FORESTS IN COMMERCIAL TIMBER REGIONS

The largest areas in urgent need of protection forests are found in the commercial forest regions of the Appalachian, Ozark, and Ouachita Mountains, the Cumberland Plateau, a few broken areas in the southern pine regions and adjoining hardwoods, and an area at the head of the Wisconsin River. These have been referred to in the discussion of the different regions and are indicated in Figure 6.

The importance, from a national standpoint, of prompt action and the great acreage that must still be left to local initiative requires that immediate steps be taken by the Federal Government toward the acquisition of more protection forests in the Mississippi Basin. With the concurrence of the State authorities, and in consultation with them to avoid conflict with any State forestry programs, the Government of the United States should approve as to purchase units all areas within the commercial forest regions meeting the standard requirements governing the National Forest Reservation Commission in the execution of the Weeks law. This, of course, limits immediate action to the scope and regions approved by the legislatures of the several States. With these points in view a number of areas considered in this study have been listed in a tentative program for the purchase of protection forests needed on the Mississippi watershed. Such purchases, if authorized, should be made by the Forest Service of the Department of Agriculture under the approval of the National Forest Reservation Commission.

TABLE 5.—*Purchase areas*[1]

Area	Acres	Area	Acres
Additions to the Ouachita National Forest in Arkansas	313, 240	Kentucky-Cumberland area in Kentucky	900, 000
Additions to Ozark National Forest in Arkansas	120, 000	Kentucky area in Kentucky	478, 000
Additional forest in Oklahoma	855, 355	Pearson Hills area in Alabama	478, 000
De Soto area in Louisiana	230, 000	Levissa Fork area in West Virginia and Kentucky	800, 000
Jackson area in Louisiana	500, 000	Tug Fork area in West Virginia	430, 000
Little River area in Louisiana	85, 600	Elk and Gauley area in West Virginia	629, 000
Licking area in Kentucky	323, 000	Homochitto area in Mississippi	25, 000
Pine Mountain area in Kentucky	450, 000	Wisconsin River area in Wisconsin	100, 000
Quicksand area in Kentucky	268, 000		
			6, 985, 195

[1] For location of proposed reservations see Figure 8.

Probably not more than 85 per cent of the total acreage of these areas would be purchasable by the Government for protection forests. No land more valuable for farming than for forestry should be acquired. In mineral regions titles should be limited to surface rights, the present owners retaining their property interest in the minerals with the right to remove them under terms equitable both to the owner and to the public. In round numbers the total of purchasable land within the areas listed is estimated at 5,900,000 acres. The cost at an estimated average of $5 per acre totals $29,500,000 or an average of $2,950,000 a year if spread over a period of 10 years.

This does not include the additional areas from which lands are being currently approved for purchase by the National Forest Reservation Commission within national forests already created under the Weeks law. The purchasable lands not yet acquired within such limits on the Mississippi watershed are estimated at about 2,642,000 acres. This added to the 5,900,000 acres additional herewith recommended would make the total of forest-land purchases on the watershed proposed as a Federal activity, 8,542,000 acres, with a total expenditure of $42,721,000 or $4,272,100 annually if spread over a period of 10 years. Including the national forests already created from the public domain or acquired under the Weeks law, the total area of protection forests owned by the Federal Government in the Mississippi Basin would thus ultimately become 25,822,000 acres. This is slightly over 16 per cent of the forest lands on the drainage, or about 3 per cent of the total area of the drainage.

Even with the Federal Government assuming this part of the burden, there are still large areas where public forests, State, county, or municipal, would appear to be the only satisfactory solution. The field for local initiative will still be large enough to tax to the utmost the possibilities of State, county, and municipal forest ownership and leave a large field for private ownership. This is particularly true of that part of the Cumberland Plateau lying within the State of Tennessee, where the State legislature has not given its consent to purchases by the Federal Government more than 20 miles west of the North Carolina boundary. The problem will also be a difficult one in the State of Mississippi. Changes in the present enabling legislation of the States, with respect to Federal purchases under the Weeks law, may require some modifications in the purchase areas listed above for Federal action.

FARM WOODLANDS

The most difficult part of the forest problem on the Mississippi drainage is that having to do with the 115,000 square miles of forest land in farms and in regions primarily agricultural. This naturally arises from diversity of area, location, character, and ownership. The problem is exceedingly complex. The land is within the absolute control of millions of individual independent farm owners who are usually unaware that other interests may be injured if the hillside forests are overgrazed, burned, or cleared off.

Though the lumberman may be fairly charged with a large share of responsibility for unwise forest destruction, it is only fair to state the fortunate circumstance that, after he has destroyed the virgin forests by utilization—wise or otherwise as the case may be—he usually moves on and leaves the field to nature and her curative processes, also, unfortunately, to the merciless inroads of repeated fires. With the farmer the situation is different. His settlement is permanent in design. His stability is nearly always a splendid virtue, invariably so if the land which he clears and cultivates is suitable for permanent farming. Where he makes a mistake and clears land that quickly loses its fertility under the wash of rainfall, he is reluctant to give up the fight. So much of his labor has gone into the land itself and must be abandoned if he goes elsewhere, that he refuses to surrender and only does so when driven to the utmost extremities of poverty. The process of trial and error in the use of land for farming was started in the Mississippi Valley by the first settlers who crossed the mountains at the headwaters of the eastern tributaries of the Ohio River about Revolutionary days and has been going on ever since.

As a people we are still somewhat young and inexperienced. Like the young man who fancies his inheritance is inexhaustible, we fancy that soil fertility is a fixed condition inherent to land in the very nature of things, and we clear land on steep slopes and use it for intertilled crops where similar land in older countries would either be kept in forest or would be terraced before being plowed. The fact of excessive soil erosion from farms is so conspicuous in every report on a drainage unit including considerable quantities of farm lands that it becomes the outstanding finding of this study.

This excessive erosion is taking place from three classes of lands: (1) Lands originally prairie which are too steep in slope for cultivation and should be kept in sod and used for pasture or hay lands; (2) lands along the margins of streams or in narrow draws where trees are the only growth strong enough to withstand soil washing and bank cutting, and most important, (3) land originally timbered on slopes too steep for tillage without terracing. In some places the proportion of such land under plow is considerable. The report on one drainage unit where soil erosion is particularly malignant shows that 30 per cent of the total area under plow was abandoned between 1920 and 1925, largely because of soil losses. The serious damage appears usually to be limited to a few acres in a place—a steep slope here, a gully there, an unprotected stream bank, or the like. However, in the aggregate much greater damage is in many regions taking place in the insidious form of sheet erosion, often without the

owner of the land realizing that injury is being done to his own property, to say nothing of the fact that a national problem is being made more difficult. The damage by gully washing is more obvious.

From any one piece of land in the Mississippi Valley the contribution of eroded soil is usually small, but the aggregate would make an impressive total. Furthermore, from certain highly vulnerable soils the contribution of silt tonnage is often enormous. In addition, the adverse effect on water storage and water flow of the neglect of a small area may be far-reaching. A single gully of less than a quarter of an acre may add more to the destructive power of a flood than the clear run-off of an entire section of well-managed fields or woods. The misuse of farm soil is not a sin peculiar to one class or region. It is far too common north, south, east, and west.

This fact of the mismanagement of farm soils runs through all the unit reports. Through all the reports there also runs evidence of mismanagement of farm wood lots owing to lack of technical knowledge or advice. The most prevailing fault is overgrazing, often to the extent of killing out all undergrowth and young reproduction within the reach of stock, exposing the tree roots as a result of soil washing and tramping, and preparing the way for the loss of protective litter from winds sweeping through the open parklike growth. All this greatly reduces the value of the area either as a timber-producing property or a soil and moisture conserving property. In most cases also the pasturage is of low value. In consequence of the overgrazing of farm wood lots and the erosion of farm lands being so general and so widespread, it appears best to cover the farm wood lot and the farm-soil erosion problem for the Mississippi Valley as a whole rather than for each major basin separately.

How to secure better management of farm wood lots is largely a question of education and extension. It involves awakening to action, based upon better understanding, the owners of the 115.000 square miles of wood lots and waste land lying within farms. The importance of this problem from a national standpoint was recognized by the Senate Select Committee on Forestry in its report which resulted in the enactment of the Clarke-McNary law, June 7, 1924. Sections 4 and 5 of this law provides for cooperation through the States with the owners of farm wood lots.

It is understood that the Senate committee's indorsement of wood-lot appropriations was based primarily on the national economic importance of the wood lots from a wood-supply and agricultural-betterment standpoint. If this work is at all worth its cost by reason of such returns, then by all means it may well be speeded up on account of its contribution to the regulation of stream flow. At first thought the use of farm woodlands may appear to be a minor factor in flood control, but such is not the case. We are dealing with very great acreages. If by the stimulation of better management of farm wood lots we can bring about an average increase of 2 inches in the layer of humus, that means an increase in water-storage capacity of 1,815 cubic feet for each acre so transformed. On a total of 115,000 square miles the increase in water-storage capacity would amount to 133,854,000,000 cubic feet, or the equivalent of the entire average run-off of the Mississippi River system above Quincy, Ill.,

averaging 72,899 second-feet, for a period of over 21 days, or a flow of 1,000,000 second-feet for over 37 hours. The resulting effect of mechanically retarding run-off would be very much greater.

We have also to consider the possibilities of forest planting on eroding farm lands as a check to erosion. Experiments conducted by the Missouri Agricultural Experiment Station showed that six plots having a gradient of only 3.71 to the hundred handled under different conditions—not cultivated; plowed 4 inches; plowed 8 inches; planted in wheat annually; planted in corn annually; rotating corn, wheat, and clover—lost soil at an average rate of 23 tons per acre a year over a 6-year period, as compared with an average annual loss of about 562 pounds on a seventh plot under sod. The farm lands in the Mississippi Valley which should be planted to forests are waste lands and lands which can not be cultivated or retained in sod as pasture or meadow land without excessive erosion. Such lands are usually much steeper than those employed in the Missouri experiment. Gradients in excess of 5 per cent and up to 15 per cent or even 20 per cent are not uncommon. Under such conditions even heavier erosion might properly be expected. Successful forest planting would in 5 to 10 years reduce the average annual loss by erosion to a negligible factor. The present appropriation of $75,000 a year for aiding timber planting on farms, under the Clarke-McNary Act, can be credited with stimulating the planting on farms of 30,000 acres during 1926, which would not have been reforested without this contribution. If half of this expenditure and half the acreage is in the Mississippi Valley on sloping land similar to that in the Missouri soil-erosion experiment, this would mean eventually the withholding of about 345,000 tons of silt burden from our streams each year as a result of this 1926 expenditure, or slightly more than 9 tons of silt for each dollar originally expended. This would make the cost to the Federal Government of a single year's service less than 11 cents a ton. Spread over a period of 11 years it would be 1 cent per ton.

But it should not be forgotten that the appropriation for planting farm wood lots was not made primarily for flood-control purposes. It was made for farm-land betterment and to help safeguard the Nation's future timber supply. Therefore, in estimating the importance of this work it must be given credit for the soil fertility which is saved from being irrecoverably lost and for the value of the wood crops, as well as for the increase in the moisture-holding capacity of the land by leaf-litter accumulation, for the greater permeability of the soil, and for the prevention of siltage in streams.

From the standpoint of the public benefits realized for each dollar of Federal money expended on flood-prevention forests, the greatest returns may be expected from that part of the Federal funds authorized to be appropriated under section 4 of the Clarke-McNary law which is used in the stimulation of planting on eroding or other waste lands in private ownership. The owner furnishes the land, plants the trees, and continues to look after them entirely at his own expense, while the most the Federal Government and State do is to help furnish the planting stock and give advice. The landowner, of course, owns the timber when it grows up, but his timber protects the watershed of the great river just as effectively as though the public had paid the entire bill.

Along with this activity must go cooperation under section 5 of the Clarke-McNary law, which authorizes the Secretary of Agriculture to cooperate with the States in assisting "the owners of farms in establishing, improving, and renewing wood lots, shelter belts, windbreaks, and other valuable forest growth and in growing and renewing useful timber crops." The close relationship between these two sections is shown by the fact that 23 States in the Mississippi drainage basin are now cooperating with the Federal Government under section 4 and 21 under section 5. Under section 4 the farmer is aided in securing suitable forest-planting stock at a cost which makes planting a practical business venture. Under section 5 he is given expert advice in caring for his wood lots and other forest growth. Planting stock and tree seeds must be provided to restore forests on the 10,000 square miles of idle or waste lands in farm ownership in the Mississippi Basin. The farmers also need advice in managing the 105,000 square miles of farm woodlands which do not require planting but whose improvement will add greatly to the protective forest cover on the drainage.

It is desirable that additional funds be provided for Federal encouragement of forest planting on lands in private ownership in the Mississippi watershed as rapidly as the States are organized to extend this work and the owners can be induced to plant up their waste and idle land or eroding slopes. The increase in funds for giving advice on the care of farm wood lots should keep pace with the needs for such service.

This is undoubtedly the most practical method of solving the forest-watershed problem on lands best suited for forest purposes in farm wood lots and regions predominantly agricultural. The expenditures by the cooperating States in this work are already more than double that of the Federal Government, although the section 4 expenditures are usually returned to them in the form of receipts from sales of planting stock. The private cooperator is enabled through the operation of this law to secure his planting stock at actual cost of production. Without such a provision the costs of planting farm wood lots are usually prohibitive.

By this arrangement the expense to the private owner of forest planting in small areas is greatly reduced and progress in this improvement of stream-flow conditions correspondingly accelerated. It is estimated that there is a total of 22,400,000 acres of waste land in the Mississippi Basin requiring reforestation, of which 6,400,000 acres are in farm ownership. While much of this land is not eroding, none of it is in a satisfactory condition from a water-storage viewpoint. In the long run it is certain that the reforestation of this land would be a splendid economic investment from a national standpoint, particularly under a policy whereby the private owner bears four-fifths of the costs. On the basis of 1926 figures, the present arrangement works out as equivalent to a Federal subsidy of about $2.50 per acre for every acre planted. However, owing to the necessity of purchasing land and starting new nurseries, the present unit costs are high. With a larger acreage and well-established nurseries, equivalent service can be furnished in the future at lower cost.

All the waste or wasting land in the basin should be reforested within 20 or 25 years. It will not be done unless strong public assistance and backing are given. Under the existing conditions the Nation appears to face a $56,000,000 task if the Government must contribute $2.50 per acre for every acre needing reforestation. It is believed, however, that with experience in planting and in managing and marketing forest products, and with the realization of the resulting benefits, the private owners will take sufficient interest in putting their lands in condition to grow steadily in value without further effort except protection from fire, so that further planting subsidy will be unnecessary. The final cost to the Federal Government of securing the restoration of the 22,400,000 acres of waste lands to forests should not exceed a total of $5,000,000 or less than 25 cents per acre. Doubtless technical advice under section 5 of the Clarke-McNary law will always be necessary, since there is always a new generation of landowners growing up and since better methods of forest management will doubtless be worked out as time goes on.

PLOWLAND ALSO NEEDS ATTENTION

Extension activities in forest planting and forest management should be coordinated with extension activities in promoting better practices in farming slope lands, such as contour plowing, crop rotation, keeping steep lands in sod for hay or pasturage, and terracing according to the degree of slope and danger of washing. Wiser selection of lands for cultivation should be urged so that on lands agriculturally submarginal, and hence more productive for forest than farm crops, agriculture should not be attempted. County agents everywhere should advise against clearing slopes for cultivation unless the owner of the land is prepared to take whatever action may be required to prevent erosion and preserve the fertility of the soil. Owners should be encouraged to check further damage to their fields not only in order to prevent soil depletion but to secure the advantage of heavier crop production which follows effective terracing and the more productive use of rainfall.

There should be no conflict between the campaign for better farm practice and that for better forest practice on farm lands. The general aim should be to protect soil fertility from being destroyed by either unwise use or neglect. Unless the farmer is prepared to prevent the rich topsoil from washing away on sloping land, he should keep it in trees. However, the forest may properly be displaced whenever the productive value of the land for other purposes makes it more profitable to so use it, taking into account the expense of terracing or other soil conservation costs, if such protective work actually follows clearing.

There will always be some erosion from farm lands and some loss of soil fertility which is avoidable only at unreasonable cost. The practical application of the remedies herein proposed would not be a burden on agriculture. Upon the other hand, heavier crops under terracing and contour plowing and through prevention of land destruction and soil impoverishment by reforestation or sodding of slopes will offset the original cost of the necessary protective measures many times over. It is estimated that within 20 years it should be possible by an aggressive campaign of education and extension

to bring about a general application of the principles stated in the two preceding paragraphs, which in turn should reduce the total silt burden now coming from cultivated fields in the Mississippi Valley to not more than 25 per cent of its present volume. Present practices would have to be changed on a very great acreage of farm land in the aggregate although on a relatively small part of the total area under cultivation. Such an extension campaign seems to be justified by its direct economic advantages. At the same time, without additional costs it would make a very material contribution to flood prevention by reducing the burden of silt and by increasing the absorptive and storage capacity of lands now most subject to rapid run-off.

No recommendations are made as to legislation, organization, or appropriations for such a campaign of extension, since it does not come within the jurisdiction of the Forest Service. It has, however, appeared necessary to consider this feature of the flood and forest problem at some length in order to determine fairly the relative importance of forestry in conserving soils and moisture on farm lands. Such a campaign of rural education falls within the field of jurisdiction of the extension service of the Department of Agriculture.

THE PLACE OF PROTECTION FORESTS IN REGIONS PREDOMINANTLY AGRICULTURAL

However, the fact must be reckoned with that there are some agricultural regions in which the problem can not be solved by the resident owners with assistance of the kind mentioned above. In some regions the broken topography and large extent of forest lands on slopes which are subject to erosion present a difficult problem, too difficult for satisfactory solution under diversified private ownership. In such places the only final answer seems to be public ownership and management in blocks of several thousand acres. Examples of this kind are not uncommon in the unglaciated region east of the Mississippi River from the mouth of the St. Croix River south to the vicinity of Beloit, Wis. Again, in the southern part of Illinois forest lands form a continuous belt stretching for many miles along the bluffs. Timbered bluffs are also not uncommon in southern Minnesota and in Iowa and Missouri. In the latter State, in regions largely devoted to agriculture, large blocks of true forest lands, rough and unsuited for cultivation, are not uncommon, particularly in the southern half of the State. Indiana, Ohio, Kentucky, and Tennessee also furnish many examples of similar conditions outside the rougher mountainous region.

In all the States named, from Wisconsin to Tennessee, practically continuous areas of forest lands in rough country, in tracts ranging from 5,000 to 50,000 acres in extent, are not unusual. Such forest lands are not within the territory which the National Forest Reservation Commission has under existing policies considered for Federal purchases. However, these rough timbered regions appear admirably suited for public forests, probably under county, city, or State ownership, and the individual States appear well able financially to assume this burden with ultimate public profit. Such enterprises, well and profitably managed locally, should go far toward stimulating local

pride and self-reliance. This, in turn, would increase local initiative, self-confidence, and self-help, which it is in every way desirable to stimulate in preference to dependence upon Federal aid and leadership.

In addition there are considerable areas of bottom lands now in forests which these States might well purchase and retain for timber production, recreation, and overflow purposes. At present high waters are allowed to spread out on such bottom lands, the current is slowed down, and the sediment settles and is kept out of the main channels. Under private ownership there is always danger of such land being diked or leveed, thereby accentuating both the local and general flood problem. The Federal Government is making a good start in purchasing bottom lands for wild-life refuge purposes along the middle reaches of the Mississippi River, as indicated in Figure 8. The purchase of critical areas of overflow lands on the tributary streams should not place an unreasonable burden on each State directly concerned.

NATIONAL FORESTS, NATIONAL PARKS, PUBLIC DOMAIN AND GAME REFUGE FORESTS

In the interest of simplicity it is desirable to deal with the national forests, national parks, and public domain and game refuge timbered lands as a separate problem from non-Federal forests. Table 6 shows by square miles the gross area of national forests within the Mississippi drainage basin by States and major basins.

TABLE 6.—*Gross areas of national forest land, by basins*

State	Ohio	Upper Mississippi	Missouri	Arkansas-White	Red-Ouachita	Total
	Square miles	*Square miles*	*Square miles*	*Square miles*	*Square miles*	*Square miles*
Alabama	57.3					57.3
Arkansas				1,651.6	798.0	2,449.6
Colorado			4,487.7	2,080.4		6,568.1
Georgia	498.6					498.6
Illinois		16.7				16.7
Kentucky	35.3					35.3
Minnesota		464.2				464.2
Montana			14,013.6			14,013.6
Nebraska			323.6			323.6
New Mexico				107.0		107.0
North Carolina	1,890.3					1,890.3
Oklahoma					96.3	96.3
Pennsylvania	1,155.1					1,155.1
South Dakota			1,986.6			1,986.6
Tennessee	1,343.8					1,343.8
Virginia	333.9					333.9
West Virginia	828.6					828.6
Wyoming			7,445.5			7,445.5
Total	6,142.9	480.9	28,257.0	3,839.0	894.3	39,614.1

On the Mississippi drainage there are also three large national parks having important bodies of timber—the Glacier, having an area of 160 square miles in Montana; the Rocky Mountain, 208 square miles in Colorado; and the Yellowstone, 2,864 square miles in Wyoming and Montana.

For the total area in the national forests and parks the general statement can be made that the continuance of existing policies will meet watershed protection requirements in a satisfactory degree.

The lands in the national forests and national parks are being protected from fire and managed either for their forest or scenic values. A considerable part of these lands within the exterior boundaries of national forests and national parks, particularly in the Ohio Basin and in Arkansas, is still privately owned. However, they are all either within purchase units or in national forests where acquisition by exchange is authorized, and ultimately all lands not more valuable for agriculture or some other purpose than for forest or park purposes may be expected to pass into public ownership unless existing laws are repealed.

But such is not the case with the forest lands of the public domain. These lands are Federal properties for which Congress has established no policy further than to restrict their addition to national forests by presidential order. There are a number of areas adjacent to existing national forests which have been examined by field agents of both the Departments of Agriculture and Interior and found suitable and valuable for national-forest purposes. Such areas have been recommended by both departments and by the National Forest Reservation Commission for inclusion in national forests, and the reports have been transmitted by the President to Congress for action. No action has been taken on these areas by that body. There are still other areas of forest lands in the public domain awaiting further consideration and study by the Forest Service, but for which the information now available is not sufficiently definite to permit the drafting of legislation in other than general terms.

Generally speaking, the remaining areas of forest lands in the public domain are not yet in bad shape from a water-control standpoint, although far from being in as satisfactory condition as the adjoining national-forest lands which have been systematically protected from fire and overgrazing for the past 20 years or more. However, with increasing demands for various kinds of wood products, these unreserved forests are eventually certain to be misused. They should be put under Federal forest management by including them in adjoining national forests instead of waiting until the damage is done and then undertaking the generation-long task of rebuilding resources which were negligently and unnecessarily allowed to be destroyed. If Congress will give the President power to act direct, the Forest Service can within 90 days submit final recommendations covering all the public lands on the Mississippi watershed in Montana, Wyoming, Colorado, and New Mexico which are suitable for inclusion in national forests. The total areas of unreserved Government forest lands on the watershed of the Mississippi River which should be added to existing national forests would probably not exceed 700 square miles.

Another Federal-land activity having a direct bearing on the Mississippi flood problem is the purchase by the Bureau of Biological Survey of the Department of Agriculture, under a special act of Congress, of the overflow lands directly tributary to the main channel of the river from Wabash, Wis., to Rock Island, Ill. This area, which is known as the Upper Mississippi River Wild Life and Game Refuge, is shown in Figure 8. Its gross area is 265,000 acres, of which 165,000 acres is land and 100,000 water.

The forests along the stream margins come within the classification of protection forests, since they are most effective in preventing the cutting of banks. Furthermore, public acquisition of these overflow lands safeguards their being held as tributary reservoir areas available during overflow periods. Under private ownership there was always the menace that at some future time they, too, would be dyked or leveed for farms, the channels narrowed accordingly, the upper flood waters correspondingly hastened, and the problem below Cairo intensified.

THE BAD LANDS AND "THE BREAKS"

Two outstanding examples of serious regional erosion of non-forest lands are so clearly connected with regions of general Federal ownership and are so important from a stream-flow standpoint that their omission from this study would be shortsighted. These are the Bad Lands and "the Breaks."

In the Missouri River Basin in North Dakota, South Dakota, Wyoming, and Montana are a number of areas, most of which are indicated in Figure 6, which are familiarly known as Bad Lands. A large portion of these lands is in the public domain and is of no known value or of practically negligible economic value. The Bad Lands aggregate about 15,500 square miles and form a great single class of land having an enormous effect on erosion and run-off.

Space does not allow a detailed description of typical Bad Lands. It is sufficient for the purposes of this circular to say that they have a clay soil and very scanty cover. The character of the precipitation of the Bad Lands regions is similar to that of the region of the Missouri experiment. Unquestionably from these areas comes a considerable part of the silt which gives the Missouri the name of "Big Muddy." In this connection it is worth while to note that the Missouri River is clear at the junction of the Jefferson, Madison, and Gallatin, at Three Forks, Mont. It is usually still comparatively clear at Great Falls and Fort Benton, once the head of navigation. Its mountain tributaries come from national forests or from two great national parks, the Yellowstone and the Glacier. They come from the regions of steepest slopes and heaviest precipitation of the northern part of the basin, but because of the protection given to these watersheds by the Federal Government's national forests and parks, the streams are clear and pure. As soon as the river begins to receive the run-off from the areas of Bad Lands it immediately takes on a muddy character which it retains until it transmits its burden of water and silt to the Mississippi River.

No data are available showing quantitatively the amount of silt contributed to the Missouri by Bad Lands areas. However, very good data have been published by the Missouri Agricultural Experiment Station showing the amount of soil eroded from a bare slope having a gradient of 3.71 per 100. In a 6-year period during which the average annual precipitation was 35.87 inches the average loss was 34.95 tons per acre annually. The average annual precipitation for the Bad Lands regions is about 15 inches. The average slope would undoubtedly be much greater than 3.71 in 100. If the Bad Lands erode as readily as the Missouri soils and in direct ratio to the total precipitation, the contribution of these 15,504 square miles would be annually $15{,}500 \times 640 \times 34.95 \times (15 \div 35.87)$, or over 144,000,000 tons.

An unpublished report of the War Department estimates the annual discharge of solid matter by the Missouri as 413,000,000 cubic yards, or, at 2,700 pounds per cubic yard, about 557,000,000 tons. It thus appears that approximately 26 per cent of the total sediment contributed by the Missouri River may come from 15,500 square miles of country, or less than 3 per cent of the watershed. If we take Dole and Stabler's figures (1909) of about 180,000,000 tons as the usual sediment carriage of the Missouri, the Bad Lands contribution is 79 per cent of the whole. This is no doubt too high a proportion.

These calculations are not presented as being of direct or immediate value in determining flood factors. They are, however, believed to be of value as indicating sources of trouble which should be carefully investigated. They make clear the fact that the great influence of these areas, and the possibilities that some means may be found to reduce their destructive power by vegetative covering, justify making the Bad Lands a matter of special research. As properties they would attract private enterprise only as they might be made to produce remunerative crops. As a Federal responsibility they present other responsibilities, such as checking the burden they contribute to the silt problem of the Mississippi and possibilities of eventual reclamation for some useful purpose.

A serious erosion problem somewhat analogous to the Bad Lands of the Northwest is presented by the Breaks of the Southwest. This is the region which marks the boundary or break between the Staked Plains of the Texas Panhandle and the lower rolling red prairie country to the east. The steepness of the escarpment between the lower edge of the Breaks and the high Plains seems to be due generally to a rock cap which underlies the plains and preserves their surface until undermined and broken off.

The rain falling on the high plains is almost entirely soaked up by the soil. The run-off, and consequently the erosion, occurs in the Breaks themselves, which extend back along the valleys being cut by the upper tributaries in Texas and western Oklahoma.

Soil erosion is extremely active through the Breaks region because of a combination of many steep slopes, scanty vegetation, abundance of easily eroded soil, and sudden hard rains. It is from this region that the Arkansas and Red Rivers draw their first great burden of silt, and it is this source of silt which the population of those two great drainage basins must reckon with in their plans for development, including the storage of water in reservoirs for irrigation, power, municipal supply, or other purposes. Unless the burden of silt carried by the local streams can be greatly reduced, the storage capacity of reservoirs in that region will be diminished very rapidly.

Merely from a flood-prevention and erosion standpoint it is believed that the Bad Lands and the Breaks are of sufficient importance to justify special study and investigation. The method of stopping erosion is a problem for research. Several species of trees and shrubs, together with many hardy grasses, grow in the regions; but the task of establishing them where extreme drought conditions prevail for long periods of time, and on bare slopes which distintegrate rapidly and wash away, promises to be extremely difficult. Meanwhile overgrazing is accelerating the progress of erosion.

It seems desirable that a special research project, for the specific purpose of working out some system of protecting the Bad Lands

and the Breaks and stopping the excessive erosion now taking place in these regions, should be undertaken. It is an interstate and national problem, and seems to be one which could best be solved in a limited period of active study as a special project. This should not be primarily a forest project, but foresters should participate in the work. What is most urgently needed is some kind of vegetative cover to bind the soil, and regulated use to prevent its destruction when once established. This cover may be trees, brush, vines, or grass, whatever proves best. The Forest Service through its experience in tree planting, its study of range plants, and its experience in practical range management, should be able to help in working out some practical remedy for each region. The major objective of the project should be to work out some means of producing more favorable conditions for run-off control and reduction of erosion, and not necessarily for developing economically valuable products; it is possible, however, that products of use in industry would be realized later.

SUMMARY OF CRITICAL AREAS

Figure 6 shows graphically the location and extent of what are reported to be the most critical areas in the Mississippi Valley, judged by their need of forest cover to prevent erosion or flashy run-off. These lands are divided into three classes, detrimental, neutral, and beneficial, according to the present condition of forest cover, and, as Table 7 shows, are located in 30 States.

TABLE 7.—*Extent of the Mississippi River Basin critical areas (gross)*

State	Influence on flood conditions			
	Detrimental	Neutral	Beneficial	Total
	Square miles	*Square miles*	*Square miles*	*Square miles*
Alabama	4,922	1,015		5,937
Arkansas	1,477	13,628		15,105
Colorado	123	108	11,251	11,482
Georgia	31	569	615	1,215
Illinois	12,598			12,598
Indiana	6,153			6,153
Iowa	17,182		275	17,457
Kansas	1,538		218	1,756
Kentucky	13,244	10,890		24,134
Louisiana	2,446	154		2,600
Maryland		461		461
Minnesota	5,538		1,056	6,594
Mississippi	10,798			10,798
Missouri	15,844	9,967		25,811
Montana		277	18,227	18,504
Nebraska	154		1,477	1,631
New Mexico			3,276	3,276
New York		308		308
North Carolina	1,169	2,261	2,400	5,830
North Dakota			133	133
Ohio	8,845			8,845
Oklahoma	16,551		677	17,228
Pennsylvania	2,907	6,245		9,152
South Dakota			2,966	2,966
Tennessee	12,706	7,399	1,907	22,012
Texas	292	3,599		3,891
Virginia		3,184	446	3,630
West Virginia	6,676	12,613		19,289
Wisconsin	8,691	2,246	846	11,783
Wyoming	46	62	18,443	18,551
All States	149,931	74,986	64,213	289,130

Table 7 deals generally with forest lands and does not include either the Bad Lands or the Breaks, which are also included in this report and recommended for special study. These areas are classified as detrimental treeless areas and embrace a total of 32,471 square miles distributed among certain Western States as shown in Table 8.

TABLE 8.—*Areas of Bad Lands and Breaks*

The Bad Lands		The Breaks	
State	Area	State	Area
	Square miles		*Square miles*
Colorado	31	Kansas	1, 646
Montana	10, 121	New Mexico	154
North Dakota	3, 845	Oklahoma	3, 861
South Dakota	1, 507	Texas	11, 306
Total	15, 504	Total	16, 967

These 32,471 square miles of critical treeless areas added to the total of 289,130 square miles of critical areas based on forest requirements makes a grand total of 321,601 square miles, gross, of critical areas out of a grand total of 1,231,492 square miles in the Mississippi watershed. This amounts to about 26 per cent of the entire watershed.

However, the only areas in which anything like 100 per cent of the acreages outlined are actually critical are the Bad Lands and the Breaks. These are not included in the following discussion, which applies specifically to areas where forests are a critical factor in run-off and erosion conditions.

Many of the areas are mapped as critical because they include a considerable percentage, usually 10 per cent or more, of lands on which the retention of forests or the restoration of forests is important to prevent flashy run-off and serious soil erosion. In some regions these lands are found in innumerable small tracts scattered throughout lands which are not critical. This applies particularly to the critical areas shown in States and localities which are primarily agricultural, and with special force to the critical areas as mapped in Illinois, Wisconsin, Minnesota, Iowa, and northern Missouri. In the region of greater forest-land density the proportion of lands actually critical in character within the areas shown as critical may run as high as 80 per cent or more. This applies particularly to the critical areas outlined in Louisiana and Arkansas, and in eastern Tennessee, Kentucky, West Virginia, and Pennsylvania.

The acreage actually critical is roughly estimated at 150,000 square miles out of the gross critical acreage of 283,000. The acreage thus estimated as critical all comes within the broad classification of forest land, actual or idle, totalling 244,000 square miles for the entire Mississippi drainage. This leaves an estimated total of about 94,000 square miles of forest land in the valley having soil and topography of such characteristics that the present or absence of forest cover has no marked influence on erosion or stream flow therefrom. The 150,000 square miles of critical acreage added to the acreage in the Bad Lands and the Breaks gives a total critical acreage of 182,471

square miles within the limitations of the study for the entire Mississippi Valley.

PUBLIC DOMAIN GRAZING LANDS

With very few exceptions, each individual drainage unit which embraces any considerable acreage of unreserved public domain suitable for grazing, is reported as being injured by overgrazing and unregulated grazing, with destructive erosion taking place over large areas. No data are available to show to what extent this results in increasing the rapidity of run-off. From a flood standpoint, except for local freshets, such increase would not be material. The burden of silt which misused grazing lands contribute to the Missouri and Arkansas must, however, in the aggregate be very great.

These lands are open to entry under the various public land laws, consequently the acreage is slowly dwindling. The total area of public lands in the Mississippi Basin, according to the report of the General Land Office of the Department of the Interior July 1, 1926, was 32,514 square miles, or 22,808,960 acres. Some of these lands are timbered, but practically all have some value for grazing. Most of these lands—31,084 square miles—are on the watershed of the Missouri River; 1,410 square miles are on the Arkansas watershed; and 20 square miles are on the Red River.

The management of these lands for grazing purposes is a problem of control. It is lack of control and not ignorance or lack of interest that accounts for misuse. There is no incentive to any stockman to avoid overgrazing the public range when the leaving of any unused forage plants for reseeding is almost certain to result in some other stockman driving in his stock and feeding off what has been so painstakingly saved.

The regulation of such public grazing lands is one of the unsolved problems before Congress. It appears useless for the purpose of this study to attempt to determine definitely their quantitative contribution to the Mississippi floods or to try to prescribe a remedy. The range problem involves many complicated economic and political factors that are so far-reaching as entirely to overshadow their importance from a flood-control standpoint. It does, however, seem desirable to call attention to the fact that under present conditions they add to the difficulty of flood control and to advocate public-range control as recommended to Congress by the Secretary of Agriculture and the Secretary of the Interior.

FINDINGS OF FACT [5]

The outstanding facts brought out by the study of the relation of the forest land in the Mississippi drainage basin to the general problem of floods appear to be the following:

The forests of the Mississippi Valley never covered more than 40 per cent of the total area of the drainage basin.

By necessary human use and by unnecessary abuse and neglect this proportion has been reduced until it is now about 20 per cent, or about 244,000 square miles.

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[5] Round numbers used generally.

A very small part of this total area of forest land is in a virgin condition, the remainder being largely cut-over, with 35,000 square miles so denuded of forest or other valuable growth as to be classified as "waste" or "idle" land.

About 115,000 square miles, of which 10,000 square miles are in the "idle" class, are in farm woodlands; and 129,000 square miles, of which 25,000 are "idle" or "waste," are within the commercial timberland class.

By reason of character of soil, topography, and precipitation the character and density of forest cover on certain of these lands have a direct relation to run-off or soil erosion or both, and on such areas forest destruction increases torrential run-off and causes serious erosion. Areas with such characteristics were therefore classified as "critical areas."

The regions classified as critical areas on the Mississippi drainage amount to 289,000 square miles, of which, upon the basis of the present tendency toward increase or decrease in the ability to help prevent floods, 64,000 square miles were found to be beneficial, 75,000 neutral, and 150,000 detrimental.

The actual acreage of critical forest land within the regions outlined is about 150,000 square miles; and the approximate distribution by class is, beneficial, 35,000 square miles; neutral, 40,000 square miles; detrimental, 75,000 square miles.

With the exception of the lands within public forests and parks, amounting to 700 square miles in State ownership and 43,000 square miles gross in national ownership, the forests on critical areas are not contributing full service in the direction of flood control. This is due largely to injury by fires in commercial woodlands and to too heavy grazing in farm woodlands.

About 700 square miles of publicly owned forest land in the Mississippi Basin adjoin existing national forests and are similar to them in character and importance from the standpoint of preventing erosion and regulating stream flow.

The adequate protection of the forests in the Mississippi Basin, as recommended by the Senate Select Committee on Forestry and as authorized by section 2 of the Clarke-McNary law, would require an annual expenditure of $490,000 by the Federal Government and $1,470,000 by private owners and the States, making a total for the Mississippi drainage of $1,960,000 annually. The present (1928) expenditure by the Federal Government is $170,000 and by private owners and States $474,000.

The upper Mississippi wild life and fish refuge area, which is being purchased by the Federal Government, safeguards the narrowing of the river overflow channel as far south as Rock Island, Ill., and is therefore a favorable factor in future stream-flow regulation.

In addition to the critical forest lands 15,000 square miles of Bad Lands and 17,000 square miles of the Breaks (although treeless) should also be classified as critical areas because of their great contributions of silt to the Mississippi flood problem. The Bad Lands appear to be responsible for contributing an annual burden of silt aggregating 144,000,000 tons and the Breaks for contributing a somewhat smaller amount.

The loss of soil by erosion from cultivated fields is a serious menace not only to the channel of the Mississippi River but to the permanency of profitable agriculture in many parts of the valley which have thus far flourished through the virgin fertility of rapidly eroding soils.

RECOMMENDATIONS

The foregoing findings of fact lead inevitably to recommendations for remedial action by the Government of the United States. This action would not take the place of levees, reservoirs, by-passes, or spillways as flood preventive measures. The action recommended is not in any way intended to minimize the necessity of such works but is supplemental thereto. The effect of such action on floods either as to volume or frequency will be slow in manifesting itself. It will be largely unrecorded for the reason that its significance will be largely in what does not happen under changed conditions but would have happened had the old order continued.

It should, of course, be understood that appropriation or expenditures are suggested or recommended only upon condition that they be made at such times and in such amounts as may be in harmony with the fiscal policy of the Government.

First in order of importance is the extension of fire cooperation under section 2 of the Clarke-McNary law. The blanket of organized protection should be extended to all forests on the Mississippi watershed as rapidly as the States and private owners are willing to undertake the work. Ultimate cost per year for entire watershed about $490,000. This includes all forest lands as well as "critical areas," for flood control, since it is impractical to attempt a definite separation into classes for protection purposes. This would be accomplished with the appropriations now authorized by the Clarke-McNary law.

Idle waste land on farms and submarginal land used agriculturally should be planted to forests under the Clarke-McNary Act as rapidly as the States and private land owners will expand such work and as cooperative expenditure will be in accord with the fiscal policy of the Government.

Instruction to owners of 115,000 square miles of forest land in farm ownership should keep pace with planting and need for advice in use and marketing forest products.

The purchase of about 2,642,000 acres of protection forest lands in national forest purchase units already approved and established by the National Forest Reservation Commission on the Mississippi watershed should be completed and in addition approximately 5,900,000 acres of protection forest lands adjoining two existing national forests in Arkansas and in 15 other units on the Mississippi drainage should be purchased. Inclusive of forest lands still to be acquired in completing units now approved under the Weeks law the total amount of land would be 8,542,000 acres. These purchases could be made under the provisions of the Weeks Act and Clarke-McNary Act during a period of from 5 to 10 years, subject to the appropriations authorized under the fiscal policy of the Government.

Protection and administration of present national forests, parks, and game refuges should be continued under present policies; and

adjoining forested areas of unreserved public domain should be added to national forests.

Investigations of the Bad Lands and the Breaks should be authorized as a research project with a view to discovering some method of preventing serious erosion.

Plan of control of public grazing lands recommended by the Secretary of Agriculture and the Secretary of the Interior should be adopted. Expense, nominal appropriation to start; after starting, activity will be self-supporting from fees.

Provision should be made for securing a permanent record hereafter of stream-flow measurements and silt content of the Mississippi River at some point below Cairo and on each of the principal tributaries entering the river below that point and data essential to a long-time study of land use and erosion remedies thereby secured.

CONCLUSIONS

If these recommendations are carried out, a reasonable effort will have been made to take advantage of the power of good forest cover to hold water and soil and thus to play its part in restraining the violence of floods and erosion. Just how great or how small this influence would be in a vast watershed like the Mississippi no one can ever say, for the forces involved are too vast and complex for measurement. Yet such quantitative measurements as are available, combined with the cumulative force of common-sense observation and circumstantial evidence, point clearly to the conclusion that this influence is too important to neglect.

The benefits of good vigorous forest cover do not end with their ameliorating effect on stream flow and silting. Keeping our forest soils in place instead of letting them waste away to clog our river channels, making those soils fully and perpetually productive—these objects in themselves justify large investments in protecting and restoring our forests. Such investments are financially sound, because they will pay interest and dividends in timber products, and the resultant benefits in river protection will be a by-product without cost.

Forest rehabilitation is not urged as an alternative to engineering works for flood control. It is supplementary to the engineering program, but it is a supplement of such importance that no complete plan of flood control can omit it.

ACKNOWLEDGMENT

Space does not permit the inclusion of the names of the various individuals and agencies who have contributed to this report. Such a list would be a directory of people interested in the conservation of forests, streams, and water resources generally in the central United States. All State foresters and other officials, local, State, and Federal, have been most helpful and generous in contributing to an understanding of actual conditions as herein reported. Space limitations also compel the omission of a bibliography.

FOREST AND FLOOD RELATIONSHIPS IN THE MISSISSIPPI RIVER WATERSHED

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INTRODUCTION

The relationship between forests and waters is perhaps most important in human economy, as far as the forest is concerned, transcending even the furnishing of lumber and other greatly needed forest products. That this is not more generally recognized and appreciated is due, first of all, to the rather common failure to understand the operation of certain basic principles involved in the interrelationship between forest and soil and the life processes of the forest. Beyond this there is the difficulty of grasping the interplay of factors, some of which are so broad and so involved as to be beyond precise measurement.

The following discussion points out some of the factors involved, shows briefly how they react to each other, and how they have been modified and changed by treatment accorded the forest. No attempt is here made to cover phases of the relationship between forests and water other than those having a bearing upon the flood problem. The emphasis is here specifically directed toward the forests of the Mississippi River Valley and their relation to the erosion and spring flood problem of the lower portion of the river.

CONCENTRATION OF HEAVY PRECIPITATION AS A CAUSE OF FLOODS

The most serious floods in the lower Mississippi River Valley are caused primarily by heavy precipitation in the southeastern portion of the major drainage. This is brought out in a general way by Figures 9 and 10, which show diagrammatically the percentage of the total annual precipitation during the season in which flood conditions develop. Normally the eastern half of the major drainage receives more than 20 per cent of the total annual precipitation during the winter months, from December to February, and more than 25 per cent during the spring months, from March to May. Furthermore, in portions of the southern part of the drainage over 30 per cent of the precipitation is received during the winter and over 30 per cent during the spring. Generally speaking, south of the Ohio River, the winter precipitation is received in the form of rain, whereas north it is largely in the form of snow, the melting of which takes place normally after the high-water stages are over in the lower river. The relationship of precipitation to flood conditions is even more strikingly brought out in Figure 11, which shows for certain crucial periods the concentration of rainfall immediately responsible for the exceptional floods in the lower Mississippi.

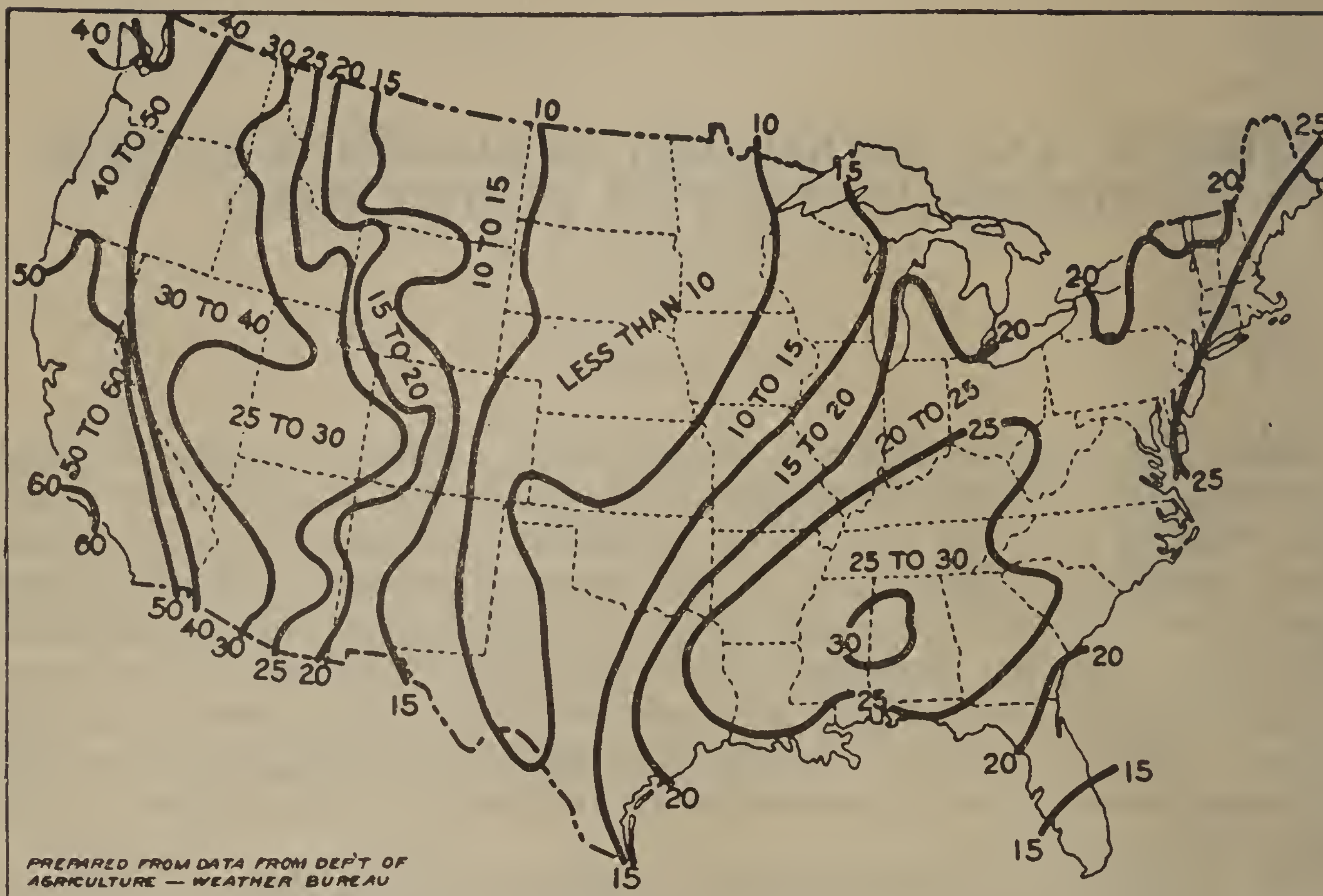

FIGURE 9.—Percentage of annual precipitation occurring during the winter months, December–February

FIGURE 10.—Percentage of annual precipitation occurring during the spring months, March–May

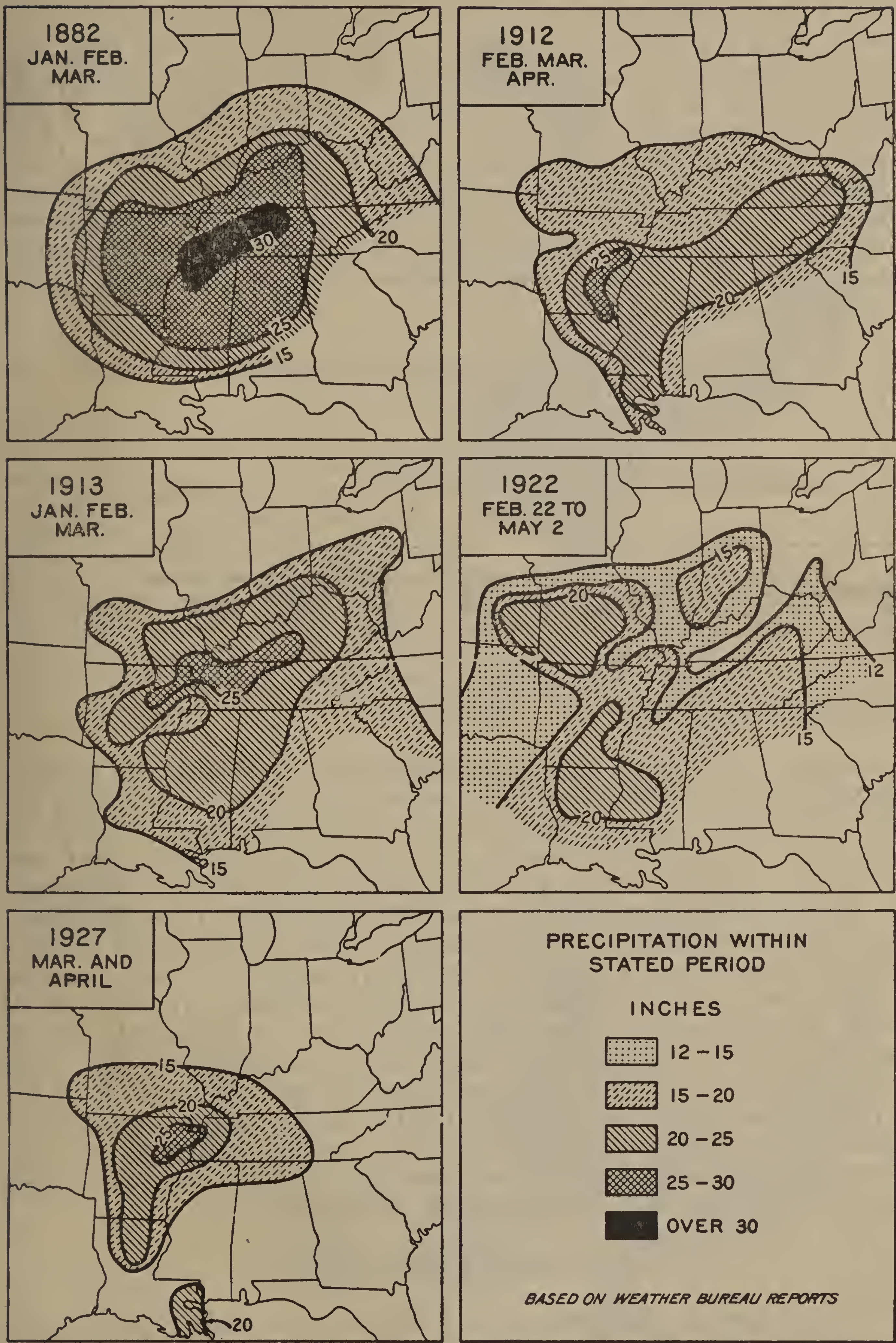

FIGURE 11.—Concentration of rainfall during storms responsible for various floods in the Mississippi River

In each of the flood years of 1882, 1912, 1913, 1922, and 1927, the precipitation responsible for these floods amounted to 20 inches or more for the 2 or 3 winter or early spring months involved. In 1882, a precipitation of 30 inches in a 3-month period was reported from a wide belt extending across northern Mississippi and western Tennessee. In 1913, roughly, this same region received 25 inches of rain in the same 3 months. In 1927, 25 inches of rain fell in Arkansas and Tennessee during March and April. This concentration of heavy rainfall in such a short period stresses the importance of the southern portion of the drainage, particularly that part in Louisiana, Mississippi, Arkansas, Kentucky, Tennessee, and southern Missouri. This is brought out in the following table, which shows the drainage basins responsible for the recent major floods in the lower river.

Percentage of flood flow in the lower Mississippi received from tributaries of the main river[1]

Tributary river systems	Flood years				Average
	1912	1913	1922	1927	
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Upper Mississippi	13	15	15	14	14
Missouri	18	13	18	15	16
Ohio	30	34	28	33	31
Other[2]	39	38	39	38	39

[1] Data from U. S. Weather Bureau—Mo. Weather Review, Supp. No. 29, "The Floods of 1927 in the Mississippi Basin," p. 31.
[2] Includes Red, Arkansas, White, and minor tributaries.

Bearing in mind the region of concentrated precipitation, and the drainage basins contributing the greatest volume of water during the flood period, the area of forest lands and their location, as shown in Figure 4, are highly significant. The greater part of the forest area in the Mississippi Basin is concentrated in that portion from which the greatest floods and highest flood stages in the river originate. Any influence that the forests exert upon water is felt in the greatest degree or can be made to be felt in the greatest degree, in the region roughly south of the thirty-ninth parallel and there any retention of water, any decrease in water flow would have an immediate, direct, and primary bearing upon high water stages of the main river. This is still clearer, in view of the location as shown in Figure 5, of the "critical" erosion areas, or forest lands that, by reason of soil characteristics, or of position with respect to heavy precipitation, slope, or topography, etc., have more than the ordinary influence upon erosion primarily, and flashy run-off secondarily.[1]

THE FOREST A BIOLOGICAL UNIT

To most people the forest is a group of trees occupying a given area and of value only from the standpoint of the lumber which may

[1] In addition to the forest lands, two other general regions are included: The "Bad Lands" of the Northwest and the "Breaks" of the Arkansas. A more complete discussion of this feature is given in The Protection Forests of the Mississippi River Watershed and Their Part in Flood Prevention. E. A. Sherman. U. S. Dept. Agric. Cir. 37, 1928. (See also pp. 1 to 51.)

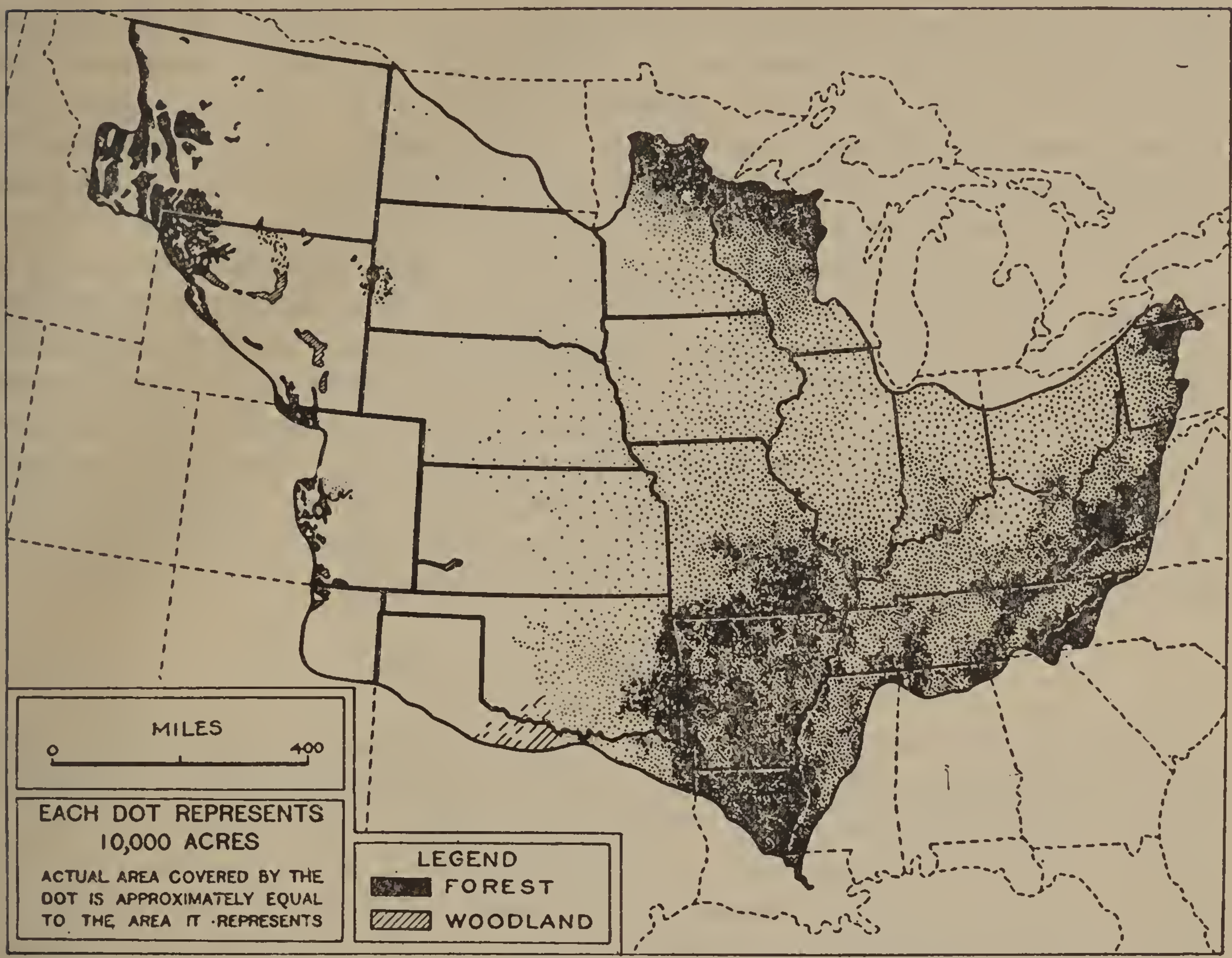

FIGURE 12.—Distribution of forest lands. Area outlined represents the gross area of the Mississippi drainage system

FIGURE 13.—Critical areas with respect to erosion

be produced or from the aesthetic viewpoint. To those who are interested in the forest from the standpoint of its relation to all human activity, the forest is seen as a living unit in itself, composed not alone of the trees, but of the underwood, the subordinate vegetation, the soil, and the animal inhabitants of the woods. It is the forest in the latter sense, the forest as a biological unit, which is in mind when the forester considers the relationship of the forest to waters.

The forest from the biological point of view therefore consists of the trees considered both as individuals and as members of a society of individuals, the subordinate vegetation found in the forest, the forest floor, and the forest soil. All of these have their part in the relationship between forests and floods, and all of them react to their environment, which is in turn influenced by the forest as a whole. Because all are important in themselves and in their reaction to each other, it is necessary to consider the more important factors separately as to their influence and their part in the problem.

FOREST LITTER AND FLOODS

Leaves, small twigs, and other débris dropping continually upon the forest floor, together with the remains of grasses, herbs, and other surface vegetation make up the forest litter. As this litter disintegrates and is worked into and incorporated with the soil by the activity of soil microorganisms, of insects, and by the action of the smaller forest-inhabiting animals, quantities of it decompose, become humus, and are added to the mineral soil. The soil of the undisturbed old-growth forest has a dense litter cover and is exceedingly rich in humus, the accumulation of years of biological activity.

This forest litter is important because of its controlling influence on water flow and erosion, for it retains a large amount of water for considerable periods by absorption, reduces run-off and so prevents soil washing, and is the source of most of the humus found in forest soils. This influence has long been known to foresters and to others, but recent studies have strongly confirmed old data and have brought very striking new data to attention. These studies indicate that the rôle played by the forest litter is far greater than has hitherto been suspected.

WATER-HOLDING CAPACITY OF LITTER

The marked water-holding capacity of surface litter varies from a small fraction of an inch to more than an inch of water, the amount so held being dependent upon the forest type, the history of the stand, and the condition of the litter.

To determine precisely the actual effect of different kinds of forest soil in retaining the water which they receive as rain or melting snow, Prof. E. Henry conducted a series of experiments with typical soils from spruce and beech forests. With the greatest care to preserve the natural arrangement and solidity of the soil, a number of soil samples were thoroughly saturated by plunging into water for several days, and were then drained of excess moisture and weighed. After being thoroughly dried at a temperature of 100° C. (212° F.) the samples were reweighed, and the weight of water held by the saturated soil thus determined. From the average of all the weighings

FIGURE 14.—The value of the forest litter is here well illustrated in these two views taken in the Appalachian Mountains. The 2-year accumulation of hardwood forest litter evident in the upper picture has been destroyed by fire on the tract pictured below. Four months' exposure of the surface soil has resulted in erosion that has laid bare the surface roots of the remaining vegetation. Such erosion is rare where the litter cover is protected and maintained

it was found that the spruce-needle humus contained, when saturated, 4.15 times its own weight in water, while the beech-leaf humus contained 5.38 times its own weight. When simply air-dried, which is, of course, the case in nature, beech-leaf humus was found still to absorb 4.41 times its weight, while air-dried spruce humus took up about 3.38 times its weight.

To ascertain the actual amount of water absorbed and retained per given unit of area by spruce and beech humus, the average weight of oven-dried (100° C.) humus per acre was determined. Allowing 15 per cent for excess moisture content of air-dried over oven-dried humus, air-dried spruce and beech humus were found to have a retentive capacity of approximately 46.44 and 22.2 tons of water per acre, respectively. This amounts in volume to 1,510 cubic feet per acre for spruce and 712 cubic feet for beech humus, which are equivalent to rainfalls of 0.41 inch and 0.2 inch, respectively.[2]

The forests of the Mississippi River, for the most part, have been greatly abused. Fire has repeatedly run through the forest both before logging and subsequently, the forest has been cut with little or no regard to its silvicultural needs, and overgrazing is common. All of these have resulted in an inadequate litter cover, a cover whose value could be greatly increased by proper forest practices.

A number of recent investigations have determined the water-holding capacity of litter from typical forests in various parts of the country. These studies, besides confirming European experience in regard to the great water-holding capacity of litter and of humus, show that under forest conditions typical of our mismanaged, burned, understocked, and overgrazed stands the forest floor has far less absorptive value than it should, and would have, under proper forestry practices.

In the Northeast the water-holding capacity of the litter ranges from 300 to 900 per cent of the dry weight of the litter, the highest values being obtained in the spruce and in the northern hardwood forests. Freshly dropped pine litter in the Lake States absorbs water to 156 per cent of its dry weight. In the Central States region the absorptive capacity of the scanty hardwood litter averages about 360 per cent. In the southern hardwood forest it ranges up to 400 per cent, and in the southern pines from 150 to 350 per cent, the lowest values being for freshly dropped litter.

In the Appalachian Mountains the water-absorptive capacity of the litter range is from 300 to 535 per cent. The average for hardwood stands was determined to be approximately 458 per cent and for conifers 344 per cent. Values as high as 890 per cent were obtained for certain material, such as the moss commonly found under laurel; for decayed logs they ranged from 343 to 537 per cent. On account of the fact that fires are common throughout the Appalachian region, these represent only the capacity of one or two years' accumulation, or a litter depth of rarely more than 2 inches.

The absorptive capacity of forest litter[3] varies, in terms of rainfall equivalent, from 0.10 to 0.93 inch. The poorest values ob-

[2] Zon, Raphael. Forests and Water in the Light of Scientific Investigations. Appendix V, final report, National Waterways Commission, 1912.

[3] Alway, Frederick J. and Paul M. Harmer; Minnesota Glacial Soils Studies: II. The Forest Floor on the Late Wisconsin Drift. Soil Science, 23. Pp. 57–69. 1927.

tained in this study were from the litter of a hardwood forest where cutting has been quite heavy and where the stand was open. The best results were obtained in a relatively dense forest of spruce, birch, cedar, and poplar, and where the forest formed a complete canopy.

In peat deposits, such as are characteristic particularly of the spruce forests of the Lake States and the higher portions of the Appalachian Mountains in the Ohio River drainage, the amount of water absorbed may easily be several inches, this amount being dependent upon the depth of the deposit. The full absorptive value of these deposits, however, is not often available because peat is seldom reduced to air dryness.

The influence exerted by litter upon the water situation of a large region can be illustrated in part by the data obtained for the Appalachian Mountains. There is every reason to believe that the values here given would be too low if applied to the whole hardwood-forest region, but they are indicative. In this study it was determined that the absorptive effect of hardwood litter is greatest on the middle and upper north slopes and lowest on the upper south slopes in the Appalachian region. On the lower slopes, according to Dr. C. R. Hursh of the Appalachian Forest Experiment Station, there is but little difference in the absorptive capacity of the litter on different aspects. In the coves decomposition is apparently so rapid that the accumulation of litter is less rapid than on the dry slopes. However, assuming similar litter conditions on south and west slopes and also on north and east slopes, the following may be considered the average of equivalent precipitation retained in the Appalachian Mountains at the present time.

Location	Area	Possible absorption of water by litter
	Per cent	*Inches of rainfall*
Upper south and west slopes	20	0.033
Lower south and west slopes	20	.190
Upper north and east slopes	20	.241
Lower north and east slopes	20	.186
Cove bottom and lower cove slopes	20	.194
Average for region		.169

This litter, however, is far from being at its best. Fires have been, and still are, prevalent in the Appalachian forests, and the old heavy litter mantle has practically disappeared. Stands are greatly understocked because of destructive logging and fires, and the soil impoverishment brought about by repeated fires and erosion.

LITTER IN PLANTATIONS

Investigations in Ohio by the Central States Forest Experiment Station indicate that comparatively young plantations have considerable influence upon flood and erosion. It was found that forest plantations ranging in age from 12 to 20 years had developed a uniform litter cover which was rapidly increasing in depth and in value. The absorptive capacity of the forest floor was determined as ranging between 100 and 250 per cent of the dry weight of the

material, indicating the possibility of an absorption of more than 0.20 inch of rainfall. This is aside from the increased water-holding capacity of the soil, brought about through the addition of humus and by the flocculation resulting from the mellowing influence of the litter and of the forest cover itself. Other fragmentary data, based largely upon observation, indicate the appreciable formation of litter and the development of forest cover conditions in from 5 to 10 years, depending upon species, location, and closeness of planting.

OTHER INFLUENCES OF FOREST LITTER

The surface litter aids further the absorption of water by helping the soil to maintain its mellowness of tilth and in other ways than by the addition of humus. It serves to keep the surface soil loose, to maintain the lower forms of animal life that assist in breaking down the litter, to increase the humic content of the soil, and to prevent soil freezing.

That a leaf litter cover tends to prevent surface soil compacting was shown experimentally by Korstian.[4] Forty measurements of penetrability indicated that bare soil had a penetrability of only 0.340 millimeter while similar soil covered with leaf litter showed a penetrability of 0.593 millimeter per gram of load applied. This is an increase of 175 per cent. Other of his investigations indicate that the leaf litter tended to equalize the soil temperature by lowering the maximum and raising the minimum. Buoyoucos[5] found that a soil covered with a mulch had a higher temperature in autumn and winter and lower temperature in spring than when not so covered, and that a bare mineral soil responded more rapidly to a change in external factors than did a litter-covered soil. MacKinney[6] found at New Haven in 1927 that litter very materially delayed soil freezing, that it kept the soil from freezing hard, and that the depth of frost penetration was diminished 40 per cent by the litter cover.

FIRES AND FOREST LITTER

The result of fire upon forest litter and its water-holding capacity is brought out by studies at the Southern Forest Experiment Station. The water-holding capacity of longleaf pine litter was but 0.02 inch for a 1-year leaf fall after fire, whereas the amount of water absorbed by the accumulation since the last fire five years previously, was 0.17 inch. The burned forest litter had an average depth of only 1 inch, whereas, in the unburned forest, the litter was 2 inches deep. Thus, doubling the depth of the litter increased the water-holding capacity of the accumulated litter eight times.

Somewhat similar results were found in loblolly pine where the amount of water absorbed by the litter from an unburned area was 0.14 inch as compared with only 0.06 inch in freshly fallen needles. In these areas the litter was of the same depth, but the increase of 233 per cent in water-holding capacity is due to the decomposition of the litter, and its transformation with humus. This serves to in-

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[4] Korstian, C. F., Factors Controlling Germination and Early Survival in Oaks. Yale School of Forestry, Bulletin 9, 1927.

[5] Buoyoucos, G. J., An Investigation of Soil Temperature and Some of the Most Important Factors Influencing It. Mich. Agr. Col. Exp. Sta. Tech. Bul. 17, 1913.

[6] MacKinney, A. L., Manuscript report, Yale Univ. 1928.

dicate part of the advantages to be derived from adequate protection from fire.

Investigations in the Lake States also show that freshly fallen litter in a Norway-jack pine forest would absorb but 0.014 inch of water, whereas older litter from a similar forest type retained on the average 0.17 inch. This increase of 1,200 per cent in the water-holding capacity is due entirely to the disintegration of the litter. Such data indicate the unseen damage that is done by fires which, in destroying the old litter, reduce materially both the water absorbed and held.

EFFECT OF GRAZING

It is significant to note the effect of overgrazed pastured forest lands upon the dissipation of litter and upon the water-holding capacity. Observations indicate a greatly reduced absorptive effect in pastured areas, where sprout growth and woody shrubs are so closely browsed that the wind can enter the woods, thereby scattering the leaves. The soil is then exposed and becomes subject to severe washing.[7] A large part of the litter is blown from the area, or scattered, or washed down the slope. In the Appalachian region it was found that only 0.02 inch of water was absorbed by the litter on a heavily grazed forest slope, whereas on similar adjoining land burned over two years previously, the water-holding capacity of the litter was 0.13 inch.

Ralph K. Day, of the Central States Forest Experiment Station, found that the litter cover was twice as deep on ungrazed as on pastured areas of beech forest. In the oak-hickory type the litter accumulation was 40 per cent greater on the ungrazed than on the grazed area. His observation was that the litter distribution was generally uniform in all cases where no grazing occurred, but was erratic wherever stock were permitted. Thus the heavier the degree of grazing the less uniform the litter, the less its depth, and the less valuable its influence upon the flood waters.

RESTRAINING INFLUENCE OF FORESTS UPON RUN-OFF

In addition to the water actually absorbed by the leaf litter and so held, there is a restraining influence which is all too often overlooked. Thus while a heavy litter cover might actually absorb and so hold against capillarity an inch or more of water, the litter by means of its arrangement and its porosity holds much more water, under certain exceptional conditions probably several times as much. Hardwood leaves curl and cup, and water is so held and restrained from flowing away. The space between the bark and the wood of twigs and branches on the forest floor is often filled with water. The spaces between bundles of needles hold water for a considerable time. The litter becomes a veritable sponge and permits the soil to absorb water.

Newly fallen litter material is not as effective in restraining the flow of water over or through it as that which is partially decomposed. Hardwood leaves of many species are somewhat slick when they first drop and water does not wet them. Fresh needles are

[7] Robinson, H. F., U. S. Indian Irrigation Service, states that the Zuni Reservoir was silted because of overgrazing, which by removing the ground cover allowed the run-off to reach the stream very rapidly and in greatly accumulated quantities. Proc. Amer. Soc. Civil Engineers, pp. 1939–1946, August, 1928.

FIGURE 15.—Above: Typical forest litter as found in the Appalachian hardwood forests. Below: The same type of ground cover four months after a light forest fire. Note the exposure of the surface soil to erosion and how completely the fire has destroyed the protecting litter mantle. Repeated surface fires not only destroy the surface cover and expose the soil to washing, but also by burning off the humus from the topsoil leave a surface less permeable to water and also less absorptive.

FIGURE 16.—On the well kept forest floor is a complete mantle of forest litter of all kinds which adds humus to the topsoil as it decomposes. This litter not only holds water itself but also increases the water-holding capacity of the soil. It also protects the soil from erosion. Fires destroy this protective mantle of litter and also burn out the humus accumulated beneath it. The result is an increase in the run-off which may well develop into severe erosion. Destruction processes of just this sort are here illustrated, first by conditions after a fire as shown in the upper plate, and then those six years after the area had been logged and burned as shown in the lower

slightly resinous and water flows off as from an oiled surface. However, as decomposition takes place and water can enter the fibers, surface tension and cohesion help to hold water. In Europe Huffel found that a forest with leaf litter, after a rainfall of from 2.4 to 2.8 inches, did not give off, even on the steepest slopes, a drop of water in the form of surface run-off. He pointed out that, if water does run off from such stands it comes from the precipitation which falls on an area deprived of its forest cover—for instance, a road.

That forest plantations influence run-off is recognized by many water companies and in New England particularly are many companies that have planted their watersheds because of the favorable influence of the forest upon the regimen of water and upon erosion. The experience of the York Water Co., York Pa., is of interest in this connection. The company has planted some 700 acres above the intake dam with about 680,000 evergreens. It has been found, according to General Manager E. P. Kable, that—

> The quality of the water in the stream has also materially improved, as there is very little erosion from the banks, and, as an example, when there was a great downpour of rain * * *, the water in this dam remained clear, whereas some of the neighboring streams became very turbid.

Recent and as yet incomplete detailed investigations by the California Forest Experiment Station indicate that the surface run-off from forest soils from which the litter has been removed, is from ten to thirty times greater than from soils with a complete and undisturbed mantle of forest litter. The reason for this is simple. The litter prevents the beating drops of rain from so rearranging the particles that they clog up the pores in the soil and cement the channel openings. In other words, with a litter mulch the rain does not disturb the surface soil by its beating action, the water is kept clean at all times as the litter and raw humus strain out any pore-clogging material, and the water reaches the soil by percolation, rather than directly, and in such a fashion that the water can be absorbed at a much greater rate than from a bare soil.

> The surface soil of a natural forest is usually covered with leaves and twigs, which protect it from erosion. It suffers little so long as this natural protection remains undisturbed. The raindrops do not usually strike the soil direct and thus destroy the granules, as they tend to do in cultivated fields. When this covering which nature provided is removed or destroyed erosion takes place.[8]

The results of the California studies above referred to indicate that the litter is perhaps the most important element of the forest in determining the distribution of rain into superficial run-off and into seepage. Still further do they show that the function of the forest litter to absorb water is insignificant in comparison with its function to maintain the percolation capacity of the soils. This operates to keep the water reaching the soil through seepage channels clear, even during the most intense beating storms, whereas the superficial rain-off on areas devoid of litter soon become muddy by picking up small particles in suspension, which were filtered out at the surface as the muddy water percolated into the soil.

To determine the effect of the percolation of both clear and muddy water through soil columns of otherwise uniform nature, a laboratory experiment was carried out. In this clear water was passed

[8] Mosier, J. G., and A. F. Gustafson, Soil Physics and Management. 1917. p. 359.

through four tubes of soil for 10 days to establish the relative characteristics of the material used. Thereupon muddy water was applied to two of the tubes, the water passing through the other two remaining clear. The percolation rate of the first two tubes dropped from a rate of 1,100 c. c. per hour to 500 c. c. in four hours, and then continuously in a parabolic curve to a percolation of 90 c. c. per hour. After another 10 days, muddy water was applied to the last two tubes of soil through which the clear water had passed at a uniform rate, and the behavior of these soils was the same as that of the first two. The results are practically identical. By this it appears evident that the sealing effect of silt filtered from percolating muddy water is sufficient to account for the increased superficial flow from denuded soils.

This experiment, highly significant in itself, only proves experimentally what has been known in southern California for many years, that muddy water may not be spread upon the gravelly débris at the mouth of the canyons if the water is to be stored in the underground artesian basin. Where muddy water has thus been distributed over the surface gravel beds, the interstices between the soil particles are effectually sealed, resulting virtually in covering the soil with an impervious layer, preventing the absorption of water into the lower soil levels. This sealing effect of muddy water on bare soils accounts in large measure for the great differences that exist between run-off from a covered soil and from a barren or denuded one. This fact has long been overlooked or minimized by those who have discounted the influence of forest and of forest cover upon run-off and upon erosion.

Studies in China of the superficial run-off from forested and denuded areas, made by Lowdermilk,[9] show the average run-off to be forty-seven times greater from the deforested than from pine-forested areas, the extremes varying between twenty-six and one hundred and thirty-two times. In spruce-larch forests in the same general region, the run-off from denuded plots ranges from fifty-two to one thousand five hundred and five times more than from the forested plots, the quantities varying with the amount, distribution, and character of the rainfall. Another part of this same study indicated that under the conditions of the experiment the forest vegetation operated to increase the absorptive capacity of the soil over that of barren soil from three to five times (averaging 3.5 times), even in prolonged rains such as 14 inches in 40 hours.

Investigations by H. S. Gilman, of San Dimas, Calif., in 1926 afford a striking illustration of the value of litter. In 1919 about 50 per cent of the area in the San Dimas drainage basin burned over, destroying completely the heavy litter and chaparral cover. By 1926 the chaparral cover had, in a considerable degree, returned, but the heavy layer of litter characteristic of the watershed prior to the fire had not yet been formed. In April, 1926, the measured flood flow in the flood-storage reservoir was 1,100 acre-feet, of which three-quarters came from the old burned-over part of the drainage. Thus as 275 acre-feet came from the 50 per cent that was unburned, the flood discharge from the entire area in this flood should have been but

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[9] Lowdermilk, W. C., Factors Influencing the Superficial Run-off of Rain. Proc. Third Pan-Pacific Sci. Congress. Tokyo. 1928.

550 acre-feet. Due to the lack of a suitable restraining influence, the litter, the discharge from the burned area was just four times what it should have been.

Thus any factor which tends to destroy the litter mantle and the humus of the soil tends to increase markedly the amount of water which flows off quickly from an area. It is obvious that any burned or any eroded soil can not retain the same amount of water as soils not so mistreated, and this superficial run-off helps to swell the flood crests of all streams. This is aside from any increase in the flood flow due to the material carried in suspension, which floats or is rolled along on the bottom, and so displaces water and heightens the flood crest.

WATER-HOLDING CAPACITY OF FOREST SOILS

It is well known to all who work with the soil, such as farmers and foresters, that humus or organic material of any kind incorporated with the soil greatly increases its water-holding and water-absorptive capacity, and investigations have shown that soils rich in humus retain against gravity several times as much water as do soils devoid of or low in humus. Hilgard [10] over 20 years ago pointed out that, in general, the loose tilth and humus content of the surface soil causes it to weigh less, bulk for bulk, than the underlying subsoil even when the latter contains more clay. Furthermore, Hilgard states, "meadows and woodlands (forest) generally show the highest humus content in their surface soils, gradually increasing while in that condition; while when taken into cultivation the humus content gradually decreases."

According to Mosier and Gustafson [11] a very favorable effect is produced upon the permeability of medium and fine-grained soils by the incorporation of organic matter, but in coarse-grained, sandy soils the effect of organic matter is to retard percolation, a thing very desirable in such soils. In silt and clay soils the irregular fragments of undecomposed parts of plants impart a porosity helpful to the downward movement of water, while the humified material aids in the production of cracks through its property of shrinkage as well as its effect on granulation, both favoring the movement of water. Porosity varies directly as the amount of organic matter. It is usually lessened by the rearrangement of the soil particles upon wetting, especially in soils low in organic matter.

"There is no better method of increasing the moisture-holding capacity of soils than by adding organic matter. It acts as a sponge itself, and when mixed with the mineral part of the soil gives higher porosity and consequently greater water capacity. It retards capillary movement in soils, as well as aids in the production of a better mulch, both of which help in retaining moisture by reducing evaporation. Sand permits of rapid percolation with comparatively small amounts of water retained. If organic matter is added to sand, the retention power of sand will be greatly increased. This table shows the effect." [12]

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[10] Hilgard, E. W., Soils. Pp. 107–108 and 133. 1907.
[11] Mosier, J. G., and A. F. Gustafson, Soil Physics and Management, p. 149. 1917.
[12] Ibid, p. 149.

Effect of organic matter on retention of moisture in sand

Soil material	Grams of water retained by 100 grams of soil	Increase, per cent
Coarse sand	13.3	
Coarse sand with 5 per cent peat	18.6	40.0
Coarse sand with 10 per cent peat	24.7	85.7
Coarse sand with 20 per cent peat	40.0	200.7
Peat	184.0	1,283.4

Recent investigations at the University of Minnesota[13] indicate that soil density, expressed as weight per cubic foot, is a reliable index of water absorption, the lighter the soil the higher the water-holding capacity. In a particular study of forest soils, it was found that the average density or weight of the surface 3 inches of forest soils studied was 53 pounds per cubic foot. The average weight of similar virgin prairie soils was 54.8 pounds. It should be borne in mind that pasture soils would show a material decrease from this figure owing to the common practice of overgrazing as well as the loss of material which would decay on the ground. "Pasture grasses are frequently eaten so closely by stock that very little benefit is derived by the soil."[14] With greater depths the weight would increase, for surface soils contain more humus than the deeper soils.

Alway and Harmer[15] also state that the weight of half a cubic foot of soil taken from the surface layer in a virgin balsam forest near Duluth was 33 pounds.

Hilgard also states that "while in peat, marsh, and muck lands the humus content may rise above 20 per cent, in ordinary cultivated lands it rarely exceeds about 5 per cent, and very commonly falls below 3 per cent, even in the humid regions."

According to King,[16] the capacity of field soils for moisture is as follows:

	Sand loam	Clay loam	Humus soil
	Per cent	*Per cent*	*Per cent*
First foot	17.65	22.67	44.72
Second foot	14.59	19.78	31.24
Third foot	10.67	18.16	21.29

This is the amount of water retained. Expressed in inches of depth, the amount so retained is:

First foot:

Sand loam	3.0
Clay loam	3.5
Humus soil	5.0

[13] Harmer, P. M., Density of the Surface Foot in Forest and Prairie Soils on the Late Wisconsin Drift. Soil Science, 23: 73–80. 1927.

[14] Mosier and Gustafson, p. 160.

[15] Alway, F. J., and P. M. Harmer, The Forest Floor of the Late Wisconsin Drift. Soil Science, 23: 67–72. 1927.

[16] King, F. H., Physics of Agriculture, p. 131. 1907.

In the second and third foot there are further differences in favor of the soil with humus, which amount to half an inch or more of water for each foot of depth.

Then, too, tree roots, by reason of their depth of penetration and spread, assist materially in making the soil more permeable to water and in leading water deeply into the soil. When these roots decay their effect is very greatly magnified.

Data thus show that, generally speaking, forest soils have a higher moisture capacity than agricultural soils. Expressed in inches, this amounts to an excess capacity of from 1 to 3 inches—due to humus alone—in favor of the well-kept forest soil, the higher value being that obtainable with the best protected and cared for forests.

Because of fires and because of mismanagement, this excess of capacity of forest over other soils is now probably closer to the minimum than the maximum. Therefore, while it may be safely claimed that the present abused forest soils retain 1 inch more water on the average than agricultural soils, because of the humus content, there is the strong probability that this could be increased to the maximum, or 2 inches more, if forest lands were properly tended.

The removal of the forest by logging, and particularly by those destructive methods which allow the surface to be bare of cover for extended periods, results normally in the destruction or dissipation of the litter without any addition to the humus content of the soil. In fact, this dissipation accelerates erosion and the washing away of the top soil with the rich humus layer. That this exposure results in the destruction of the litter is due to the fact that its transformation into absorbable humus requires relatively even and uniform moisture conditions, not too great fluctuations of temperature, and the activities of biological agencies which do not function under such exposure. Generally speaking, ideal conditions prevail under a dense, uniform forest cover.

DELETERIOUS EFFECT OF FIRES ON SOIL

The effect of the removal of the forest cover is further marked if fire burns over the area, for not only does the fire destroy the litter, the source of humus, but it also destroys the humus in the top layers of the soil and prepares the way for a rapid disintegration and erosion of the surface soil. This is the more marked the greater amount of débris present, and fires following logging are exceedingly destructive because of the great amount of fuel and the resultant prolonged high temperatures. These affect materially soil characteristics other than that of humus content. Any such fire on cut-over areas involves the loss of much soil through erosion; with nothing to stop the flow of water, and with gullies already formed by logging, the rate of surface run-off is accelerated, and erosion, both of the sheet and of the gully type, is the more pronounced.

What this means in terms of organic matter content, and hence in the water-holding capacity of the forest soil, is shown by work at the University of Minnesota.[17] Studies indicate that following

[17]Alway, F. J., and C. O. Rost, Abstract in Proc. First Int. Congress Soil Science. Pp. 67–69. Washington, 1927.

the forest fires near Duluth in 1918, the loss in soil organic matter varied from 7 to 26 tons per acre. As the experiments of Wollny [18] indicate that the water-holding capacity of humus is four times its own weight, the loss due to fire amounts to an average of about 75 tons of water per acre, or expressed in inches of depth, between one-half and three-fourths of an inch of water.

Investigations also show that the loss in the water-holding capacity of surface soils following a severe fire in a brushfield or "elfin" forest in southern California amounted to 6.1 per cent.[19] Subsequent deterioration of the site due to high temperatures, low rainfall, and no litter accumulation involved further losses, so that seven years later the total loss amounted to 19.8 per cent, or approximately one-fifth of the total.

Snyder [20] gives the following:

> The soil from Hinkley, Minn., before the great forest fire of 1893 showed 1.69 per cent humus and 0.12 per cent nitrogen. After the fire there were present 0.41 per cent humus and 0.03 per cent nitrogen. The forest fires had caused a loss of 2,500 pounds of nitrogen per acre, or 13 tons of organic matter.

This amounts in water-holding capacity to approximately three-fourths of an inch of water.

Even those light fires which run over the surface and apparently consume only the loose litter are a material source of loss, and the effect of such fires is augmented if they are repeated frequently.

> Fires of even moderate intensity destroy large amounts of organic matter from the immediate surface, and even in the burning of straw, stubble, or corn stalks considerable organic matter is lost from the soil.[21]

In many parts of the country "light-burning" or "woods-burning" is still practiced and is particularly prevalent in the regions of the Mississippi below the Ohio and Missouri Rivers. Data collected by the Forest Service show that in the Mississippi drainage, reported forest fires burn over annually between seven and eight million acres in the States south of Kentucky and Missouri. As the data are complete for only a portion of the area it is believed that the total area annually burned is well in excess of 12,000,000 out of a total of approximately 80,000,000 acres of forest land.

More recently, Dr. S. C. Vandecaveye of the Department of Agronomy of the State College of Washington at Pullman, made some investigations of soils that had been burned over. He reported to the Pacific Northwest Forest Experiment Station as follows:

> With regard to the matter of structure I will say this. The structure of the soil is largely controlled by its colloidal material which consists largely of finely divided inorganic substances, such as iron aluminum silicates, and of finely divided organic material which is in the final state of decomposition. In the soils in question the organic colloids were naturally all destroyed by heat, and much of the inorganic colloidal material was probably also changed in form. The result is that the moisture in such soils is not retained readily because the colloidal material which has a tremendous moisture-absorbing capacity is destroyed temporarily. The action of weathering, which naturally brings mineral matter in solution, gradually restores the inorganic colloids and thus restores the original water-holding capacity of the soil; so that, with

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[18] Wollny, E., Ueber den Einfluss der Pflanzendecke auf die Wasserführung der Flüsse. (Vierteljahresschrift des Bayerischen Landwirthschaftsrathes, 1900. v. 5, 389–445.)

[19] California State Board of Forestry, Report on Concurrent Resolution No. 27, Erosion and Flood Problems in California. Pp. 21–22. 1923.

[20] Snyder, H., Soils and Fertilizers. P. 111. 1908.

[21] Mosier, J. B., and A. F. Gustafson, Soil Physics and Management, p. 152. 1917.

the exception of the organic colloids, the burned soil in a humid section should be fairly well restored in the course of four or five years. As to the organic material, it is quite obvious that it takes a very long time to bring such soil back to its original condition, but I do not think that this should interfere very much with the growth of seedling trees, except that they would not grow as fast as in the better soils.

INFLUENCE OF FOREST UPON EROSION

That forests have a marked influence upon erosion can not be seriously questioned. All the evidence collected by foresters and engineers supports this fact, and the literature upon the subject is voluminous. The material carried by streams rising in forested areas is, generally speaking, of an organic nature. When silt or mineral matter is so carried, this is the result of exceptionally severe conditions and is decidedly out of the ordinary. Waters from all other classes of lands carry heavy loads of soil, the amount and character depending upon the character of cover, nature of the soil, and the disturbance to natural conditions that washes have made.

Bennett[22] has shown that the rate of erosion from grassland in North Carolina was four hundred and fifteen times slower than on bare ground of the same slope, while at Columbia, Mo., the rate of erosion from sod land was one hundred and thirty-seven times slower than from bare ground plowed 4 inches deep. Thus grass is very efficient not only in restraining soil erosion but also in conserving rain water. Bennett points out that these results are highly suggestive of the powerful restraint exerted by forests upon erosion and run-off, as a tree cover is more efficient than grass in the retention of both soil and water. Furthermore, Bennett states—

> If grass sod in the Piedmont enables an important agricultural type of that region to hold back 51 per cent more of the rainfall than bare ground and 33 per cent more than fields planted to cotton, what saving are we to expect from a well-forested area with a good ground cover of woods mold consisting essentially of peat, knowing that some forms of peat are capable of holding water in excess of one thousand times their own weight?

At the Morgan Falls plant of the Georgia Railway & Power Co. on the Chattahoochee River, which is below large cultivated areas, the reservoir in 1904 covered 750 acres. After 10 years' service the reservoir capacity was gone, the reservoir having silted shut, leaving only a channel through the center for the river flow. On the other hand, the Mathis Reservoir, above which is only forest, after 10 years' service shows little or no sign of silt whatever.

R. G. Tyler,[23] professor of sanitary engineering, Massachusetts Institute of Technology, states that the character of the drainage area is an important factor with reference to silt production. With similar soil conditions, open, cultivated tracts erode more than wooded or grazed areas. He also stated that the conservation of forests and the reforestation of denuded areas have a beneficial effect in decreasing siltation difficulties.

The most recent data as to the effect of forests upon the material carried by streams draining into the Mississippi River were developed in a study in North Carolina following heavy precipitation

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[22] Bennett, H. H. Geographical Relation of Soil Erosion to Land Productivity. Geographic Rev., pp. 579–605, October, 1928.
[23] Proc. Amer. Soc. Civil Engineers, pp. 2367–2369, October, 1928.

received in August, 1928. Water samples were taken from a number of streams. In the French Broad River, at Rosmen, N. C., where 90 to 95 per cent of the area above the point of sampling was in forest, the amount of suspended matter in parts per million on the basis of dry weight of suspended matter was but 11, consisting mostly of particles of organic matter with some fine sand. On the same river, at Long Shoals Bridge, near Asheville, with only 40 to 45 per cent of the watershed drainage above point of sampling in forest land, the amount of suspended matter was 107 per million, consisting of silt, clay, fine sand, and organic matter, or an increase of 850 per cent. So also Dillingham Creek (1½ miles below Dillingham, N. C.), where the basin is 95 per cent forested, had only 4 parts per million of organic matter in the samples taken; whereas a tributary of Big Ivy, with only 10 to 15 per cent of its drainage area in forest and with much cultivated land, carried 4,370 parts of solid matter per million. Hominy Creek, at the Brevard Road Bridge, near West Asheville, with approximately one-third of its drainage in forest, carried 3,405 parts of eroded matter per million.

In commenting upon these results Dr. C. F. Korstian, of the Appalachian Forest Experiment Station, states that the streams with a high percentage of forest cover were strikingly clear while the streams containing large amounts of cleared land were unusually turbid.

One of the first things done by erosion is to remove all loose organic matter not thoroughly incorporated with the mineral soil. This takes place from practically all soils.

> Organic matter may be removed from the soil by erosion. Very few regions are so flat or have the soil so well protected that there is not more or less erosion taking place, and in the more rolling areas this becomes a very active agent in the removal of the organic matter along with the soil. In this way in certain regions almost all of the surface soil and its organic matter have been removed.[24]

Thus the bare soil sheds more water than the litter-covered soil, and erosion, through removal of the loose humus, still further reduces the water-holding capacity of the soil.

Because of the lack of this absorptive cover, and because of the beating action of rain which disturbs the soil particles, the surface water soon becomes muddy, and the penetration of water is reduced. This greatly increases the surface run-off and paves the way for erosion.

In addition to the removal of loose humus by superficial surface run-off, the top soil is further depleted by reason of sheet erosion, acting more or less uniformly over the surface, and by gullying. As erosion proceeds at an ever-accelerating rate, the more material removed from the surface the less its water-holding capacity, the greater the run-off, and the more severe the erosion. The removal of the top soil exposes the subsoil, which washes more rapidly than the surface soil, because it is always less pervious to water. Thus the lack of a cover, the lack of a good forest floor, the lack of humus in the top soil, each serve to speed water on its way and to cause greater floods and heavier soil losses.

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[24] Mosier, J. G., and A. F. Gustafson, Soil Physics and Management. Pp. 151–152. 1917.

How much this amounts to when one considers the lowered permeability of the soil, the decreased water-holding capacity, and the increased superficial run-off, has never been exactly determined. It is sufficient, however, to state that it is enormous. Although detailed reliable data are unfortunately unavailable, the following statement by Bennett [25] has particular significance:

> Inadequacy of measurements makes it entirely impossible to estimate the full relationship of soil erosion to floods. There is evidence, however, to indicate that erosion always tends to increase the volume of floods materially. There is abundant proof of this for the smaller streams, and it has not been proved that the same sort of thing does not take place in the larger streams, as the Missouri and Mississippi. We have entirely too little evidence relating to the rains that produced some of the earlier floods so often referred to by those who profess to believe that only conspiring rains and inadequate levee protection have anything to do with such disastrous floods as that along the Mississippi in 1927; and also there are too few precise data relating to these early floods themselves. It would not, however, in the least vitiate the argument of those who see a vital realtionship between floods and denuded watersheds if some of the earlier explorers had looked upon floods in the Mississippi that very greatly exceeded the one of 1927, for there was then as now no natural law against overwhelming downpours. There is abundant evidence upon the pages of the world's history that every now and then all the probabilities have been rudely upset. This being true, they may be upset again. The important thing for mankind is not to permit improbable eventualities and unavoidable actualities (the rains) to constitute a negativating deterrent in the setting up of obstacles to those wasteful processes going on under more or less normal conditions.
>
> The largely increased run-off and wash-off from unprotected slopes as compared with protected slopes can not but add volume to the water of rising streams. Equilibria of current and load, balances of deposition and resuspension, eroding banks, eroding flood plains, etc., enter into the process, of course; but an increased volume of water in a stream is a definite enlargement that can not be decreased except by part of the water getting away somewhere; and the place most of it must go is the sea, where it arrives as quickly as possible and in as large volume as possible, regardless of the methods of travel involved.
>
> It is perfectly obvious that if a greater portion of water and of suspended and dissolved matter is withheld from the streams the flood hazards which occur at peak stages will be greatly relieved; and, furthermore, both the water and the soil are needed in the fields and pastures where they belong.

TRANSPIRATION OF FORESTS

That plants and forests use water is generally known. This use is more marked during the period of rapid growth than at any other period because of the important part played by transpiration in the tree's growth. Forests, because of the large evaporation surface afforded by their dense foliage, because their irregular crown canopy is fully exposed to wind and sun, their wide spreading root systems, and their longer vegetative activity, use more water than do agricultural crops.

Although the actual specific quantity of water used by forests and by crops is not known, a reliable index of this use is furnished by studies of the water used by individual plants under controlled conditions. Experience indicates that the hardwood tree species found on moist sites use more water than do the softwood species on dry sites, and that during the vegetative season the amount of water transpired by forests of various species ranges from 3 inches for

[25] Bennett, H. H., Geographic Relation of Soil Erosion to Land Productivity. Geographical Review, pp. 579–605, October, 1928.

pines to 11 inches for beech, while species of moister habitats require even more. In any case, the amount of water used depends in a large measure upon the location of the forest, the character of the soil, and the character of the season.

Hohnel [26] estimates that a fully stocked beech stand, 115 years old, consumes in a year from 1,560 to 2,140 tons of water per acre, a quantity that may be more easily vizualized in acre-feet. If all this water were spread over an acre, it would have a depth of 1.15 feet. If an acre contains 526 trees from 50 to 60 years old, the water consumption is only 1,026 tons per acre, or 0.7 acre-foot; and if it contains 1,620 trees, only 35 years old, the consumption is as low as 321.5 tons per acre, or 0.23 acre-foot. Hohnel expressed the quantities of water that were transpired in 1880 in percentages of the precipitation of that year (31.5 inches). He found that elm transpired 43.5 per cent, beech 25 per cent, and birch 40 per cent of the precipitation.

Ney [27] computed, on the basis of Hohnel's results, the amount transpired during the entire vegetative season by beech as 10.8 inches, spruce 8.3 inches, and pine 2.9 inches; or, for the mixed forest as found in Europe, as 7.3 inches. In the case of conifers the amount transpired during the winter must be taken into account, and this would make the transpiration of pine for the entire year 3.1 inches and for spruce 9.1 inches.

As may readily be realized, the demand of forests for water, as well as the amount used by them, is greater in the earlier part of the growing season than later, and the draft upon the soil water is heaviest in the early spring. Thus, even before leafing actually takes place, roots are active and much water is being taken into the tree.[28]

How much water is so absorbed may be illustrated by the sugar maple tree.[29] Sap, from which the sugar is made, starts running 3 to 5 weeks before leafing, and flows freely up to about the time of leafing. When leafing begins, depending upon weather conditions, the exudation of sap practically ceases. So, while the trees may to all appearances be inactive for a month or more prior to the bursting of the buds, they are actually during this period making a heavy demand upon the soil for moisture.

Investigations in Vermont [30] show that, although there is practically no transpiration from the maple during the winter, the tree accumulates much water during the winter and early spring period. In December the water content of the trees studied was 31.5 per cent

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[26] Zon, Raphael, Forests and Water in the Light of Scientific Investigations, pp. 28–30.

[27] Ney, C. E., Der Wald und die Quellenbildung. (Forstwissenschaftliches Centralblatt. 1901, p. 452.)

[28] The amount of water which trees contain is liable to variation, just as is the case in herbaceous plants. Th. Hartig, and more especially R. Hartig, have shown that the wood usually contains more water in summer than in winter, the minimum commonly occurring in autumn, the maximum in spring. The data obtained by Geleznow and Duhamel agree with these results. In spring the accumulation of water causes a considerable internal pressure to be developed, while when the leaves expand the amount of water which the stem contains undergoes a marked diminution. In deciduous trees the spring maximum is more marked than in evergreens, as might naturally be expected, since the evergreens begin to transpire actively immediately the external conditions become favorable. It is hardly surprising that the curves obtained for different plants should not be precisely similar and that variations may be shown in different years. During a prolonged rainy period the wood will undoubtedly contain more than the normal amount of water, while under special conditions a daily variation may become perceptible. (Pfeffer, Dr. W., The Physiology of Plants. 1880; vol. 1, p. 233.)

[29] Bryan, A. H., W. F. Hubbard, and S. F. Sherwood: Production of Maple Sirup and Sugar. Department of Agriculture Farmers' Bulletin 1366, 1924.

[30] Jones, C. H., A. W. Edson, and W. J. Morse: The Maple Sap Flow. Bulletin 103, Vermont Agricultural Experiment Station. 1903.

and by the middle of March 36.5 per cent based on the dry weight of the wood. In the latter part of April the maples were found to carry 47 per cent moisture. This was reduced to 26 per cent in the summer season. The average water content of sugar maple during the period when the trees are tapped was 32 per cent, while at the same time in other trees, including ash, beech, birch, butternut, elm, and hornbeam, the water content was from 41 to 56 per cent. All this was before the buds opened. As these investigations were made in Vermont with a season some six weeks later than that of the southern part of the Mississippi Valley, it can be readily realized that the forest takes an appreciable amount of water from the soil during the period when floods occur.

Agricultural crops, including pastures, also use and transpire water during the flood period, but their draft upon the soil water is much less than that of forests. For one thing, there is but little area in growing crops in the Mississippi Basin during the flood period, and for another, the water demand of the crops that are growing is far less than that of forests because of the absorption of water by forests in advance of active vegetation, and because of the greater use of water during the early vegetative period. As most agricultural crops develop their foliage gradually, they can not be compared in any way to the rapid, indeed almost sudden bursting into leaf, of extensive areas of forest.

In considering the transpiration of water by forests and its effect upon the flood stages of the main river, the forests of the Rocky Mountain region and those roughly north of the Ohio and Missouri Rivers, or the 39th parallel have been eliminated from consideration; this first of all to be thoroughly conservative, and second because the northern and western forests are not vegetatively active during the high-water stages of the main river and because these forests are so far removed that their influence is not so marked as those of the lower basin. Their influence is felt, however, for these forests remove water from the soil and so from the streams, and the reduction of any amount of water in the streams of these regions, however small, means just that much water removed from the lower basin, and from the floods in the lower river. It is here assumed that the forests of the lower river use but 8 inches of the precipitation annually received, an exceedingly conservative figure and probably but 60 per cent of the actual requirements. Particularly is this figure conservative for the lower part of the Mississippi drainage where by reason of latitude the vegetation has a long growing season, and much more favorable climatic conditions obtain than those found in the European tests from which the figure is adapted. During January and February active vegetative growth takes place only in the extreme southern portion of the Mississippi Basin, but by March active growth is in progress as far north as Arkansas, and by April is in full swing in the bulk of the forest lands south of the 39th parallel. Since at least 25 per cent of the total water transpired by the forests is absorbed by them during the flood period, forests in this region should remove during the time when flood conditions are most severe and the need of aid is most acute, more than two inches of water per acre from the soil.

However, it should be realized that these forests are not in the best of shape. Fires, overcutting, and the lack of care have so reduced the

stands that the drain upon the soil water is less than that above stated. Because of forest conditions, the amount of water taken from the soil by the present forests may be conservatively considered as not over 1 inch.

It should not be forgotten that conifers such as the pines, and other evergreen trees, such as the live oaks, transpire water throughout the entire winter. Although the amount so transpired is, relatively speaking, small, it is taken from the soil, and so does provide for added water storage. As there are in the lower Mississippi River Basin many million acres of coniferous forest, the amount of water removed from the soil and evaporated is, in the aggregate, measurable and significant. Under full forest conditions, these coniferous forests would take from the soil during the winter a total of more than the .50 inch of water per acre, but, applying this value to the forests of the lower Mississippi, we have elected to take less than half this amount, 0.2 inch. This has been prorated in its effect over the lower drainages. It should be remembered also that for reasons of conservation solely, there has been excluded from consideration here the effect of coniferous forests elsewhere in the basin, and has been considered as applying to only 3,000,000 acres although the actual area in coniferous forest in the lower Mississippi Valley is much larger. Also from consideration here has been excluded the area in coniferous forest elsewhere in the basin as a conservative measure although the water stages in all streams are reduced to some extent by winter demands of conifers for water.

SUMMARY

In summary of the effect of forests upon the flood situation in the Mississippi River drainage it may be said that the forest assists in reducing floods (1) through the water absorbed by the forest litter; (2) through the mechanical hindrance of superficial surface run-off by reason of the forest litter; (3) through the greater absorption of water by forest soils; and (4) through the use of water by the forest.

It has been shown that the value of the forest floor in conserving water can be measured. By absorption of water the litter in the uneven, unkempt, and uncared for stands of the Mississippi River drainage keeps from the streams water to the average amount of 0.2 inch of water in depth over the entire forested area in the Mississippi drainage.[31] Under a full protective forest cover such as could be brought about through adequate fire protection and adequate silvicultural management of forest lands, and reforestation where needed, the forest floor should so develop that it would become capable of absorbing at least one full inch of water. Its effectiveness would thus be increased five times.

In addition to the water absorbed, there would be the amount mechanically restrained from superficial run-off. Although European data place this value at nearly 3 inches of water for a good forest cover, the conservative figure of 1 inch is adopted for purposes of this discussion. Because of its poor condition, the restraining

[31] It is believed that the earlier assumption of 0.25 inch of water restrained by the litter is too great. The Protection Forests of the Mississippi River and Their Part in Flood Control. Department of Agriculture Circular No. 37. (See also pp. 1 to 51.)

effect of the litter is reduced still further and placed on the same basis as adsorption. Therefore the amount of water so held back under present forest conditions is estimated at only 0.2 inch. Under good forest cover and proper forest management, this may readily be increased significantly.

Forest soils have a greater absorptive capacity than do other similar soils by reason of their humus content. The greater absorption of forest soils over similar land in agriculture, in spite of the present lack of forest management, amounts to at least 0.25 inch of water over the forested area on the most conservative basis. Fully productive and protected forest soils should conserve a full inch more water than similar land not in forest.

Forests by preventing erosion and by holding back superficial run-off also affect the amount of water in streams during flood. This reduction in superficial run-off has been figured as ranging from several hundred to several thousand per cent. Although the difference in run-off due to the forest cover can not be expressed in depth of water in inches over the entire drainage basin, the amount so held would, in the aggregate, amount to a very large figure. This would markedly affect the flood crest. More data on this score are needed.

Forests use water in their development. On a most conservative basis, and applying the data only to the forest areas which would affect the spring floods of the lower Mississippi, this usage of water by transpiration would amount to 1 inch in depth over the area concerned. With forest management adequately applied to the region this draft upon the soil water would easily and quickly be raised to at least 2 inches.

Then, finally, the winter transpiration of conifers, although slight, makes a draft upon the soil water and so provides for additional water storage. This draft is here placed at 0.2 inch based on an acreage far below the area actually in coniferous forest and discarding large areas in conifers in the Rockies and in the upper Mississippi Basin.

It should be remembered also that the stabilizing influence of forests upon superficial run-off and upon flashy flood stages is here disregarded because of the lack of specific and detailed data, although it is known that this effect is enormous.

Then, too, it should be remembered that the erosion phase of the flood flow is disregarded—an important item since silting has a decided bearing upon reservoir capacity, and indeed, upon all measures where the control of water is involved.

Thus, all in all, the measurable effect of the present forests, during the period when flood stages occur in the lower Mississippi, is to withdraw from the soil a considerable quantity of water. With proper care and management this amount could be greatly increased in some portions of the area becoming as much as 5 inches during the time when it has an appreciable effect upon the flood stages of the river. This depth of water, when applied over the forest area concerned, becomes a factor of major importance in any plan of flood control. As the data here used are in every case conservative where forest influences are concerned, the actual influence of the forest is much beyond that here given.

Maj. Gen. Edgar Jadwin's report of December 1, 1927, contained in House Document No. 90 of the Seventieth Congress, first session, transmitted to Congress in the message from the President on December 8, and entitled "Flood Control in the Mississippi Valley," states (p. 19) that "studies of the reservoir board have shown that, to reduce the flood stage in the Mississippi by 1 foot it is necessary to store from 7,000,000 to 11,000,000 acre-feet of water." Assuming 10,000,000 acre-feet as the average reservoir storage equivalent to 1 foot of water in the river at flood stage, the water retained by the forest can be expressed as "reduction in inches of the flood crest," or in terms of "reservoir capacity."

What this amounts to under present forest conditions, what it could amount to under forest management, and what this means for each of the drainage basins and for the river itself, is given in the following table:

Restraining influence of forest cover—Reduction in flood height

Drainage basin	Forest area	1 inch of water on forest area	Absorbed by litter		Additional retained by litter	
			Present, 0.2 inch	Possible, 1 inch	Present, 0.2 inch	Possible, 1 inch
	Square miles	*Cubic feet*	*Inches*	*Inches*	*Inches*	*Inches*
Ohio	68, 223	158, 496, 000, 000	0. 87	4. 36	0. 87	4. 36
Upper Mississippi	49, 076	114, 013, 000, 000	. 63	3. 14	. 63	3. 14
Lower Mississippi	17, 925	41, 643, 000, 000	. 23	1. 15	. 23	1. 15
Red-Ouachita	26, 372	61, 267, 000, 000	. 34	1. 69	. 34	1. 69
Missouri [1]	17, 600	40, 888, 000, 000	. 22	1. 13	. 22	1. 13
Arkansas-White [2]	35, 909	83, 424, 000, 000	. 46	2. 30	. 46	2. 30
Rocky Mountain province [3]	21, 135	49, 832, 000, 000	. 27	1. 35	. 27	1. 35
Total	236, 240	548, 806, 000, 000	3. 02	15. 12	3. 02	15. 12

Drainage basin	Water absorbed by forest soils		Transpired by forest				Total	
			Growing season, to Apr. 1		Winter-period conifers [4]			
	Present, 0.25 inch	Possible, 1 inch	Present, 1 inch	Possible, 2 inches	Present, 0.2 inch	Possible, 0.5 inch	Present	Possible
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Ohio	1. 09	4. 36	(5)	(5)			2. 83	13. 08
Upper Mississippi	. 78	3. 14					2. 04	9. 42
Lower Mississippi	. 29	1. 15	1. 15	2. 30	0. 02	0. 05	1. 92	5. 80
Red-Ouachita	. 42	1. 69	[6] 1. 31	[4] 2. 62			2. 41	7. 69
Missouri [1]	. 28	1. 13					. 72	3. 39
Arkansas-White [2]	. 57	2. 30	2. 30	4. 60	. 05	. 10	3. 84	11. 60
Rocky Mountain province [3]	. 34	1. 35					. 88	4. 05
Total	3. 77	15. 12	4. 76	9. 52	. 07	. 15	14. 64	55. 03

[1] Only the forested area in Missouri and southwestern Iowa adjacent to the regions of heavy precipitation here included.
[2] Only the forested area in Arkansas, Missouri, and eastern Oklahoma within the Ozark province and adjacent to the flood zone here included.
[3] The woodlands of the semiarid plains, and forests of the Rocky Mountains are grouped in this unit.
[4] This includes data only for 3,000,000 acres of coniferous forest south of the 39th parallel.
[5] For conservative reasons only no influence is credited the forests of the Ohio Basin, although water withdrawn from soil by forests in the southern portion of drainage at least could very justifiably have been used.
[6] A considerable area of brushy, scrubby growth has been eliminated because it is distant from and not strictly comparable with the balance of the forest growth considered.

It is patent, therefore, that the present mismanaged forests of the Mississippi River exert an exceedingly important influence upon the water. But it is difficult so to express this influence in readily understandable terms. Recently, however, a way has been provided and the forests may now be really appreciated.

The reduction in flood flow due to the influence of forests has been here expressed in inches of flood crest on the Mississippi based on General Jadwin's statements. This shows that under the present conditions forests are responsible for 14.64 inches of water, which could by proper protection, proper care, and proper management be raised to 55.03 inches. And this reduction is made at the source and the water does not have to be handled in any way by human contrivances.

Expressed in terms of reservoirs, the present forests in the Mississippi River drainage exert a beneficial influence upon the flood flow equivalent to 1.26 reservoirs of 10,000,000 acre-feet capacity. Properly protected, cared for, and managed they would be approximately equivalent in their beneficial influences to 4.6 reservoirs.

These natural reservoirs are not subject to silting. They are perpetual in their influence and they pay their own way. They require only an interest in their well-being and an appreciation of their worth. They do need to be put in order.

RECOMMENDATIONS

The preliminary report upon forest conditions in the Mississippi drainage contained in the Department of Agriculture Circular 37, "The Protection Forests of the Mississippi River Watershed and Their Part in Flood Prevention,"[32] made a number of recommendations for remedial action by the Federal Government. The additional data and further study have only served to strengthen these suggestions and to change only in certain particulars, and those chiefly in emphasis, the conclusions reached.

In this earlier report the complete protection of forest lands from fire was given primary emphasis. The absolute need and necessity for this is further brought out by the facts as to the influence of the litter upon water retention, run-off, and erosion. Organized forest-fire protection is not only necessary from the standpoint of continuous forest crops but is also one of the essential forestry measures in flood control. Every effort should, therefore, be made by the Federal Government and the States to provide the essential forest protection to all portions of this region, as provided in section 2 of the Clarke-McNary Act. Prompt remedial action is essential.

Second in the original recommendations was the extension of the cooperative forest planting as authorized by section 4 of the Clarke-McNary Act that idle and waste submarginal lands may be forested. Results will be of almost immediate value from a flood standpoint through increased local water retention and decreased superficial flood flows, and through decreased erosion. Planting is also important in many of the critical areas. It is of particular importance in the loess region from the Ohio River southward, southwestern Wisconsin, and in the Ohio River drainage.

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[32] See also pp. 1 to 51 of this report.

For the most part owners of submarginal or forest lands in the critical area region of the Mississippi are unacquainted with the needs for the proper protection of their forests, and are lacking a knowledge of how best to treat these lands. Media by which this knowledge can be imparted already exist in part, but the agencies concerned are physically unable to accomplish the desired ends. To accomplish these ends an increase in forest extension activities under existing authority is needed, and further authority to carry this extension to other than woodland owners, as provided in the Clarke-McNary Act, is necessary.

The protection and administration of the national forests, parks, and game refuges under present policies should of course continue, and adjoining forested areas of unreserved public domain should be added to the national forests to insure the protective benefits found in organized Federal administration.

There is need for the prompt extension of public ownership into and over many critical forest areas; first, in order that the Federal Government may have the direct jurisdiction necessary to enable it to reduce flood flows from lands which, under private ownership and by reason of lack of suitable cover, contribute superficial run-off unnecessarily large and destructive; second, to enable the Federal Government to protect heavy necessary investments in flood-control structures, the permanency of which would otherwise be jeopardized by serious erosion. In addition, such public forests would be of great value as a source of wood products certain to be urgently needed by industry, and would demonstrate the importance of contributory indirect benefits from forests.

Within purchase units already approved by the National Forest Reservation Commission there is a total of 2,642,000 acres of purchasable land still to be acquired as a part of the Nation's forestry program. In addition, the reports indicate that approximately 6,000,000 acres more should be promptly purchased and administered as public forests as a necessary step toward Mississippi flood control. This, too, must be done by the Federal Government, since the States within which the lands are located are not financially prepared to assume such a burden, organized to administer such properties, or sufficiently interested directly to realize the necessity of such purchases.

Such a public program would include only the most urgent critical areas. For the better management, protection, and reforestation of the remaining 125,000,000 acres of forests and forest land on the Mississippi watershed not in public ownership, reliance is being placed on individual and corporate effort, stimulated by Federal and State cooperation and leadership. It remains to be seen how far such a plan will be found adequate to meet the situation. If success exceeds reasonable expectations, it may be possible to reduce somewhat the total area to be finally purchased. On the other hand, if private forestry, even under stimulation of Federal and State assistance, fails in any substantial measure to meet the requirements of satisfactory stream-flow regulation and soil conservation, to that extent its replacement by public forestry is inevitable. The only other alternative would be to classify flood destruction and soil depletion as less troublesome and costly than the cure, an admission of weakness and incompetence too distasteful for the people of this country to accept.

In addition to the forest areas, that because of its relationship to the flood question should be in some form of public ownership, there are other areas that should also be considered in any comprehensive plan for the Mississippi. These include the swamp and regularly overflowed lands from Cairo to the Gulf, " backwater " lands, and the two great floodways in the Boeuf Basin and the Atchafalaya. As shown on the map of the "Alluvial Valley of the Mississippi River," [33] there are some 6,048,000 acres of this character, involving about 2,138,000 acres of cleared land and 3,910,000 acres of swamp and timber land.

The place of these lands in the economics of the Nation should be considered. There is no question but that the forest area should continue to produce forest crops as forests are not subject to great damage from overflow. There is some question, however, as to whether it would not be sound economics, nationally speaking, to have much of the present cleared area also in forest.

From a standpoint of fertility alone, these backwater and overflow lands are agricultural beyond doubt. Their position, however, and the possibility of their being subjected to periodic and sustained overflow by reason of flood control works already erected or planned makes some of them submarginal in character. Agriculture as a permanent industry in backwater areas which are subject to great hazards has little hope of profitable returns over a prolonged period. Already controversy has developed in some quarters as to the final disposition of the lands concerned. Possibly public ownership and their devotion to forest would solve the problem, and put them to their highest economic use.

A vital relationship exists between the condition of the forests on the Mississippi watersheds and the regimen of that stream. This is most important and direct as to the areas classified as " critical." The more complete the forest cover the more conducive to regularity of stream flow. Completeness of cover depends upon adequate fire control and the proper silvicultural treatment of the forests themselves. In places this may involve planting, in others better handling of the forest as a growing crop. Where misuse of the land may jeopardize heavy investments in flood-control structures or nullify public effort in safeguarding more extensive areas from flood damage, it may be necessary for the Government to regulate the use of such critical areas, providing equitable compensation for any additional burden resulting from such requirements as are necessarily imposed upon the owner for the greater public good.

The intimate relation of the critical areas to erosion and to stream flow brings out the necessity of determining the quickest possible methods of restoring and maintaining a vegetative cover upon them. This involves investigations into the ways and means of arresting erosion already in progress by forestry measures, the determination of the best species of plants for revegetating denuded and eroding lands and the conditions under which they should be used, and research investigations into proper management of range and pasture and forest lands.

[33] House Document No. 90; 70th Cong., 1st sess. Special Report of the Mississippi River Commission on Revision of Plans for Flood Control of the Mississippi River. Nov. 28, 1928.

These investigations should be carried on simultaneously at several places in the Mississippi Valley. They are badly needed in the loess region on the east side of the Mississippi River, in the loess section of southwestern Wisconsin, in the rolling or plateau lands of the lower Ohio River drainage proper, and in the mountainous section of the Appalachians. They are also needed in the Arkansas "Breaks," in the northwestern "Bad Lands," and at several places in the open-range lands. As a part of this work, a study is needed in the Appalachians to determine quantitatively the actual effect of the forest upon the régime of streams, and upon erosion.

Such investigations are badly needed and should be undertaken with the least possible delay. They call for cooperative effort on the part of such bureaus of the department as the Forest Service, Public Roads, Chemistry and Soils, and the Weather Bureau. Such cooperation will insure that all phases of the problem are properly correlated and developed.

CONDITIONS IN THE DRAINAGE AREAS

In order to show the conditions in the forest areas of the Mississippi River, the Mississippi River Basin has been divided up into a number of regions. For these, regional reports have been prepared and are submitted as parts of this discussion. They are followed by appendices which give for each of the separate drainage units, the present conditions of that unit.

PART I

FORESTS AS A FACTOR IN FLOOD CONTROL WITHIN THE UPPER MISSISSIPPI RIVER BASIN

By

RAPHAEL ZON

Director, Lake States Forest Experiment Station

CONTENTS

PART I

FORESTS AS A FACTOR IN FLOOD CONTROL WITHIN THE UPPER MISSISSIPPI RIVER BASIN

ACKNOWLEDGMENT

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THE BASIN

The upper Mississippi Basin is that portion of the watershed lying above the mouth of the Missouri and that portion in Illinois between the mouth of the Missouri and the mouth of the Ohio. The upper Mississippi Basin occupies the north central part of the United States, including Minnesota, Wisconsin, Iowa, Illinois, Indiana, Missouri, and a few square miles in South Dakota and the northern peninsula of Michigan. The sources of the upper Mississippi River are almost exactly in the center of the continent on an east and west line. The area of the basin is 186,853 square miles, or about 15 per cent of the entire Mississippi watershed. By States the drainage basin is divided as follows:

States	Area	
	Square miles	*Per cent*
Minnesota	47, 535	25. 4
Illinois	44, 538	23. 8
Wisconsin	38, 382	20. 6
Iowa	38, 781	20. 8
Missouri	13, 448	7. 2
Indiana	2, 971	1. 6
South Dakota	1, 163	. 6
Michigan	35	
Total	186, 853	100. 0

The upper Mississippi River Basin, for purposes of this survey, is divided into 16 major drainage basins. (Table 1.)

In a basin as large as that of the upper Mississippi it is natural to find a variety of conditions of soil, topography, precipitation, and vegetative cover. One finds in this basin hills and level land, high bluffs and alluvial bottoms, lakes and swamps, and prairie and forest.

DIVISIONS OF THE BASIN

On the basis of the forest cover the upper Mississippi River Basin may be divided into three parts:

(1) The region of conifers or mixed conifers and northern hardwoods (beech, sugar maple, birch).

(2) The region of oak and its associates.

(3) The prairie region.

TABLE 1.—*Areas of the major river basins*

[Square miles]

Drainage areas	Illinois	Indiana	Iowa	Michigan	Minnesota	Missouri	South Dakota	Wisconsin	All States
Mississippi above St. Paul					20, 449				20, 449
St. Croix					3, 553			4, 111	7, 664
Chippewa								9, 379	9, 379
Black								2, 920	2, 920
Wisconsin				35				11, 868	11, 903
Minnesota			395		14, 706		1, 163		16, 264
Iowa and Cedar			11, 488		1, 008				12, 496
Kankakee	2, 217	2, 971							5, 188
Skunk			4, 323						4, 323
Des Moines			12, 780		1, 333	71			14, 184
Des Plaines	1, 304							121	1, 425
Rock	5, 321							5, 444	10, 765
Illinois	20, 744							887	21, 631
Kaskaskia	5, 812								5, 812
Big Muddy	2, 402								2, 402
Mississippi below St. Paul	6, 738		9, 795		6, 486	13, 377		3, 652	40, 048
Upper Mississippi watershed	44, 538	2, 971	38, 781	35	47, 535	13, 448	1, 163	38, 382	186, 853

Each of these drainage basins is discussed in detail in Appendix I of this report.

1. *The region of conifers and northern hardwoods.*—The region was originally entirely forested and still has over two-thirds of the land in large contiguous bodies of forest of one kind or another. The prevailing forests are of pine on the sandier soils, of pine mixed with northern hardwoods on the heavier soils, and of spruce, fir, cedar, and tamarack in the swamps. It is also a region of numerous lakes. From 5,000 to 6,000 lakes, nearly all of which are near the sources of the main river and its northern tributaries, are found within this region. In addition, there are vast swamps, some of which have been drained. The swamps and the lakes form a great natural storage for steadying the flow of the streams.

The southern boundary of this region runs from east to west as follows: From Kilbourn northwest to Black River Falls; thence to Eau Claire and St. Croix Falls, Wis., or Taylors Falls, Minn.; thence west to Rush City; thence to Milaca; thence to Little Falls and Wadena; and thence north to Itasca Lake.

2. *The oak region.*—The oak region originally was covered in large part with hardwood timber, typical of the central hardwood region,

interspersed with small areas of open prairie. The forest still occupies from one-third to two-thirds of the land area, but, as a rule, is not in large, contiguous bodies. The principal species are the oaks,

The southern boundary of this region follows a line drawn diagonally from the northwest in a southeasterly direction through Douglas, Stevens, Meeker, McLeod, Sibley, Le Sueur, Rice, and Dakota Counties in Minnesota, and through the southern part of the State of Wisconsin, within such counties as Grant, Iowa, Lafayette, Green, Dane, and Rock, to the eastern boundary of the watershed.

South of this line is the third division of the upper Mississippi watershed.

3. *The prairie region.*—The region is largely of treeless prairie, in which the forest has always occupied less than one-third of the land area and has for the most part been confined to the bluffs or to the bottom lands along watercourses.

CLIMATE

The average annual precipitation increases from northwest to southeast. It is between 25 and 30 inches in Minnesota, between 30 and 35 over the Wisconsin portion of the watershed, and over 35 inches in some parts of Illinois. The spring precipitation similarly increases from northwest to southeast. In the Minnesota portion of the watershed less than one-fourth of the precipitation (about 6 inches) comes during the spring months of March, April, and May; in the Wisconsin portion of the watershed also about one-fourth (8 inches); and in Illinois nearly one-third (10 inches). Most of the precipitation occurs during the spring and summer months. The distribution of rainfall by months, as given for Wisconsin, is characteristic also of other parts of the watershed, although the actual amounts show a slight variation.

The intensity of precipitation—i. e., whether the rain falls uniformly through a long period or quickly in the form of storms—has a direct bearing upon surface run-off and erosion. In the upper Mississippi watershed rainfall of over 1 inch in 24 hours is not a rare thing. Such rains may occur four times each year in the northern portion of the watershed and more frequently in the southern. Rainfalls exceeding 2 inches in 24 hours may occur, on the average, once a year. Rainfalls of 4 inches in one day are on record. The intensity of rainfall increases from the north to the south of the watershed.

The winter precipitation in the form of snowfall decreases from north to south. In the northern portion the average annual snowfall ranges from 40 to 60 inches. In the central oak belt it is between 30 and 40 inches, and in the prairie portion of the watershed it is between 20 and 30 inches.

The winter in the upper part of the watershed is severe; snowfall is heavy throughout the greater part of this area and lasts for considerable periods; ice forms to a thickness of 1 to 2 feet and lasts from three to four months. The streams and rivers are icebound during the winter. The mean annual temperature is about 49 degrees, and the lowest winter temperature is 32 degrees below zero.

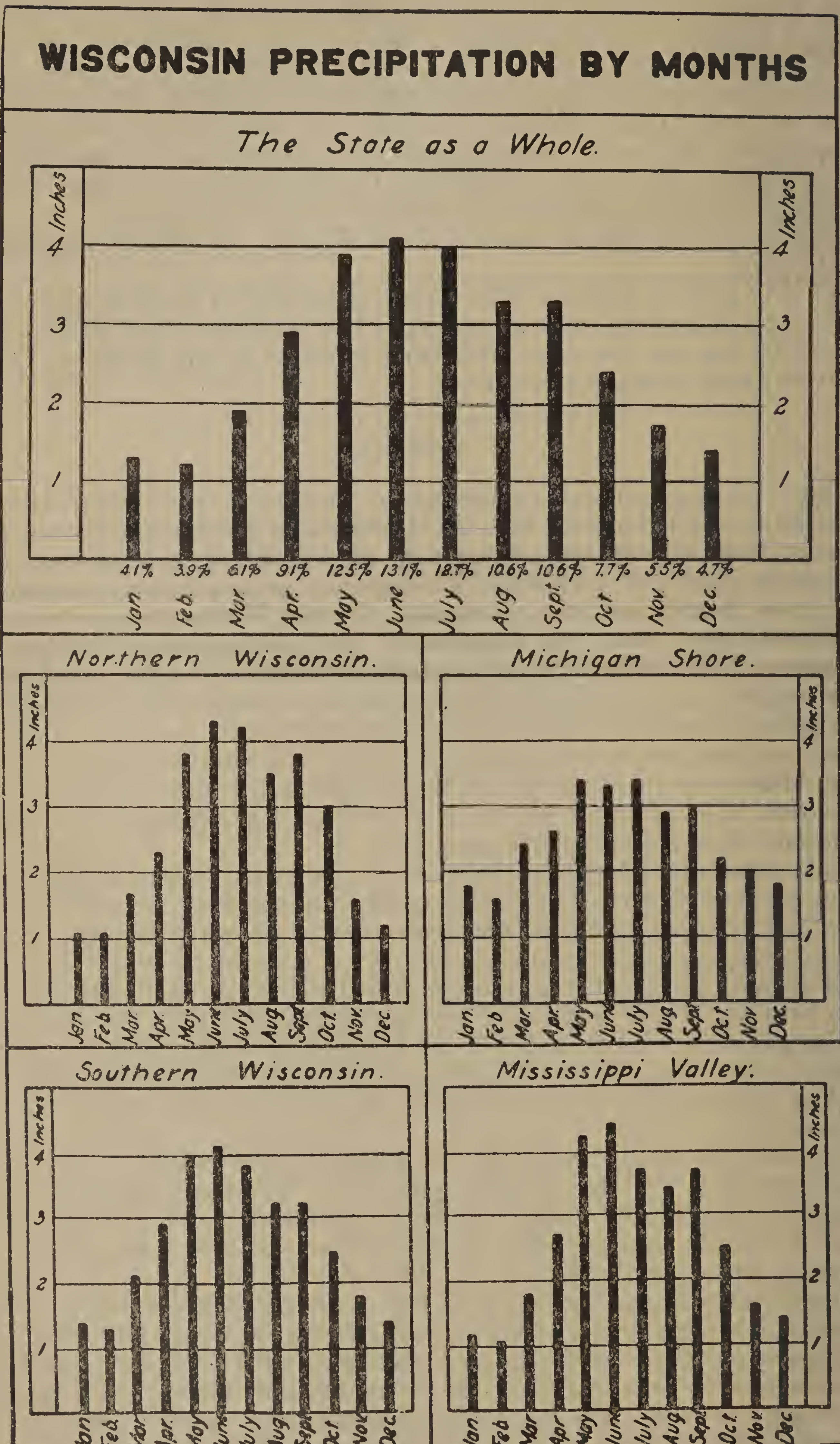

FIGURE 1.—Wisconsin precipitation by months

In the hardwood and prairie regions of the watershed the winters are much milder, average snowfall is less, the mean annual temperature is 56 degrees, with the lowest winter temperature in the extreme southern part of the watershed 16 degrees.

ALTITUDE AND TOPOGRAPHY

There are no mountain chains within the upper Mississippi watershed. For the greater part, the land is slightly rolling, lying mostly at an elevation between 750 and 1,500 feet above sea level. The differences in elevation, as can be seen from the table below, are small and are of little consequence in affecting stream flow.

Areas at different altitudes

Altitude (feet)	Square miles	Per cent
0–100		
100–500	6,727	3.6
500–1,000	93,987	50.3
1,000–2,000	86,139	46.1
Total	186,853	100.0

The topography, on the whole, is rather flat except for occasional morainic hills and the unglaciated portions of the watershed. In the unglaciated areas the land is cut deep by streams and eroded ravines. This gives the land a pronounced dissected topography. It is this dissected topography, together with the high bluffs flanking the Mississippi and some of its principal tributaries, that is of greatest significance from the standpoint of surface run-off and erosion. Only about 15,000,000 acres or about 13 per cent of the total watershed may be classed as rough or broken topography.

SOILS

The soils of the upper Mississippi watershed are extremely varied in character, and though their influence upon stream flow and erosion is largely affected by the topography, the physical character of the soils themselves plays a very important part.

For a general discussion the soils may be considered in three broad classes:

1. The upper portion of the watershed is entirely glaciated and its soils therefore consist of morainal material of gravel, sand, and silt, and of outwash sands from these mixed masses, the sands usually lying in comparatively flat plains. There may also be occasional small areas in which masses of heavier soils have been deposited, but these also are too flat to be readily eroded. The morainal masses consist for the most part of ridges and hollows, the latter in many instances without outlets. In consequence a great deal of the precipitation which falls in this region is compelled to seek an outlet by subterranean routes; and the character of the soils, freely interspersed with gravel and bowlders, is conducive to this. Streams

which find their way through this irregular topography are fed mainly by seepage from the kettle holes and lakes, and surface run-off is reduced to a minimum. It is for this reason that a great proportion of the land around the headwaters of the Mississippi and its tributaries can not be considered of critical importance, since a forest cover can add very little to the receptiveness of the soil or change the normal course of seepage water. The exceptional areas are those which have sufficient relief so that the longer slopes tend to erode and to bring surface water to the streams. Some such areas are described under "Broken Topography at the Headwaters of Streams."

2. The soils of the second general class found in the drainage basin are those of the unglaciated regions of southwestern Wisconsin and southeastern Minnesota and in the immediate vicinity of the Mississippi River farther south. Since this region has not been covered by the loose, mixed deposits of glaciers, its soils consist for the most part of residual silt loams derived from the sandstones and limestones. On the higher ground such soils are often only from 2 to 4 feet deep, a fact which in itself probably tends to cause surface run-off and erosion since it limits the capacity of the soils to absorb water. Where the soils have been transported and deposited to greater depths in the depressions they are usually both fine and relatively loose so that water cuts them readily. This territory, which is most strikingly exemplified in the bluffs of sharp relief along the Mississippi River in lower Wisconsin and Minnesota, undoubtedly presents the greatest hazard as it is unquestionably the territory in which the primary erosion process is still in progress.

3. The soils of the third class found in the region are the deep deposits of most of the southern portion not in the immediate vicinity of the Mississippi River which are commonly described by the name "loess." Whether these soils are wind-blown or deposited by ice sheets at a much earlier time than the northern glaciated areas is immaterial to this discussion. The thing which characterizes them is their great depth and fineness. They are usually typified by about a foot of black loamy soil on the surface, and by many feet of lighter colored clayey material forming a subsoil the porosity of which has not been augmented by humus. So long as the porous black humus layer remains in place the soils usually do not erode rapidly or excessively, unless it be from the deep, loose deposits along streams which are always very readily carried away. Once the porous covering has disappeared, however, as a result of cultivation, oxidation of the humus, and imperceptible sheet erosion, the whole erosion process is greatly accelerated. It is this condition which must be guarded against both for the salvation of agriculture and for the protection of streams. Even intermittent forestry on such lands offers promise of material benefit if it is conducted in such a manner as to provide for a return of the black humus-soil covering.

STREAM FLOW AND FLOODS

The streams of the northern part of the watershed, as a general rule, carry but little sediment. The streams of the southern portion almost invariably carry some sediment, the amount becoming much

greater after heavy rainstorms. Some of the streams carrying sediment, before entering the Mississippi River, pass through lakes where most of the material in suspension is deposited. They emerge, therefore, from the lakes into the Mississippi River as clear streams. Lake Pepin, for instance, was formed as a result of the sediment carried by the Chippewa River, and it still acts as a settling basin for several small streams flowing directly into the Mississippi.

Most of the rivers are subject to freshets and frequent floods. This is especially true of practically all of the streams of southwestern Wisconsin, southeastern Minnesota, Iowa, and Illinois. Those streams are subject to freshets and floods not only every spring but after every heavy rain.

The frequency of flood stages, judging by the figures of the United States Weather Bureau,[1] has been increasing in the Upper Mississippi watershed. The part which the upper Mississippi watershed, exclusive of the Missouri, plays in the flood conditions of the Lower Mississippi is of secondary importance to that of the Ohio River Basin. The flood peaks of the Missouri and upper Mississippi River never equal the extreme flood stage from the Ohio Basin, but tend to prolong it and thereby cause serious damage. Flood conditions in the rivers of the upper Mississippi watershed occur as a general rule from April to June and only occasionally in the fall.

A study extended from 1871 to 1926 of the time crest floods from the several Mississippi tributaries pass Cairo, Ill., shows that the crests of the yearly spring floods in the Mississippi River at St. Louis have come at different times over a period of years from March 10, at the earliest, to July 25, at the latest. The average date for the whole series is May 20.

The Missouri River crests, as measured at Herman, Mo., just above its mouth, come at a similar period during the spring with the average date for the whole series June 3, 13 days later, on the average, than for the Mississippi.

The Ohio River, as measured at Paducah, Ky., has flood crests from January 14 to April 30, the average date being March 5 or more than two months earlier than the average flood crest of the Mississippi.

The flood crests on the Mississippi as measured at Cairo, Ill., reflect the combined effect of the upper Mississippi, Missouri, and Ohio Rivers. The records of flood crests at this point include only one crest each year, and that one is the highest of record that year. The dates of crests at Cairo range from January 17 to May 9, with an average date of March 9. What actually happens at Cairo is that a series of crests each spring pass that point. Only the highest one for the particular spring is recorded as the crest for that year. Usually this highest crest results from a flood coming down the Ohio River, and the lesser crests which follow one to two months later from floods in the Mississippi and Missouri Rivers are not recorded as the flood crests for the year, because they are lower than the earlier crest from the Ohio. It is for this reason that the graph of the flood crests of the Mississippi at Cairo, which represents the com-

[1] U. S. Department of Agriculture, Weather Bureau No. 792. Monthly Weather Review, Supplement No. 22. The Spring Floods of 1922. By H. C. Frankenfield, meteorologist.

bined Mississippi, Missouri, and Ohio Rivers, corresponds, in the average date of the flood crests, much more nearly to the flood crests in the Ohio than it does to those of the Mississippi and Missouri.

VEGETATIVE COVER

The forests occupy some 31,409,000 acres, or 26 per cent of the entire upper Mississippi watershed; cultivated land, 62,961,000 acres, or 53 per cent; and grass land, 25,216,000 acres, or 21 per cent. By States, the vegetative cover is shown in Table 2.

Only a small area of the old forest still remains within the Upper Mississippi watershed, yet there is practically no land denuded entirely of a forest cover. The cut-over lands, even when burned, have invariably come up to second growth, especially on the heavy soils, just the soils which are subject to erosion. Where the cutting and burning have come nearest to destroying the forest is on the light sandy soils, originally covered with pine forests. These soils, being deep and permeable, form a natural ground-water reservoir whether the forest is present or not. Though most of the original forest has been cut, the forest cover still persists on the heavier soils and continues to perform its function in protecting erodible soils. Where, however, as for instance on the unglaciated soils of the Upper Mississippi, from southern Wisconsin and Minnesota southward, the slopes have been cleared and cultivated, erosion has taken place and is becoming a serious menace both to steam flow and agriculture.

TABLE 2.—*Character of vegetative cover by States*

State	Forest cover		Cultivated land		Grassland		Total	
	Acres	Per cent	Acres	Per cent	Acres	Per cent	Acres	Per cent
Wisconsin	13, 168, 000	54	7, 065, 000	29	4, 331, 000	17	24, 564, 000	100
Minnesota	11, 143, 000	37	14, 265, 000	47	5, 015, 000	16	30, 423, 000	100
Illinois	2, 200, 000	8	21, 090, 000	74	5, 214, 000	18	28, 504, 000	100
Iowa	2, 127, 000	9	15, 221, 000	61	7, 473, 000	30	24, 821, 000	100
Michigan	22, 000	100					22, 000	100
Missouri	2, 434, 000	28	3, 850, 000	45	2, 323, 000	27	8, 607, 000	100
Indiana	304, 000	16	1, 103, 000	58	494, 000	26	1, 901, 000	100
South Dakota [1]	11, 000	1	367, 000	50	366, 000	49	744, 000	100
Total	31, 409, 000	26	62, 961, 000	53	25, 216, 000	21	119, 586, 000	100

[1] Including the Little Minnesota River basin.

PROTECTIVE VALUE OF FOREST COVER

In the past it has been generally assumed that the forests of the upper Mississippi watershed are of no significance in stream control. The comparative flatness of the watershed, the prevalence of sandy and gravelly soils, and the abundance of lakes and swamps, have all seemed to minimize the protective value of the forest. The old forest has been removed, the land burned; yet the streams arising in northern Minnesota and Wisconsin are free from sediment. Is not this a direct proof that the forests have no significance in controlling flood conditions in the upper Mississippi Valley? This

generalization was based largely on observation of the streams in the northern part of Minnesota and Wisconsin, which were investigated chiefly for water power development. Only within the last few years the agricultural colleges have become alarmed over the enormous erosion that takes place on farm land cleared on sloping ground or from wooded slopes burned, or heavily grazed. The drainage of many swamps in the northern part of Wisconsin and Minnesota, followed in many cases by drying up of small streams and shallow lakes, also focused attention on the value of the upper portion of the watershed as a regulator of stream flow and lake levels. The water-power engineers in their study of the rivers were particularly interested in impounding the water for power development

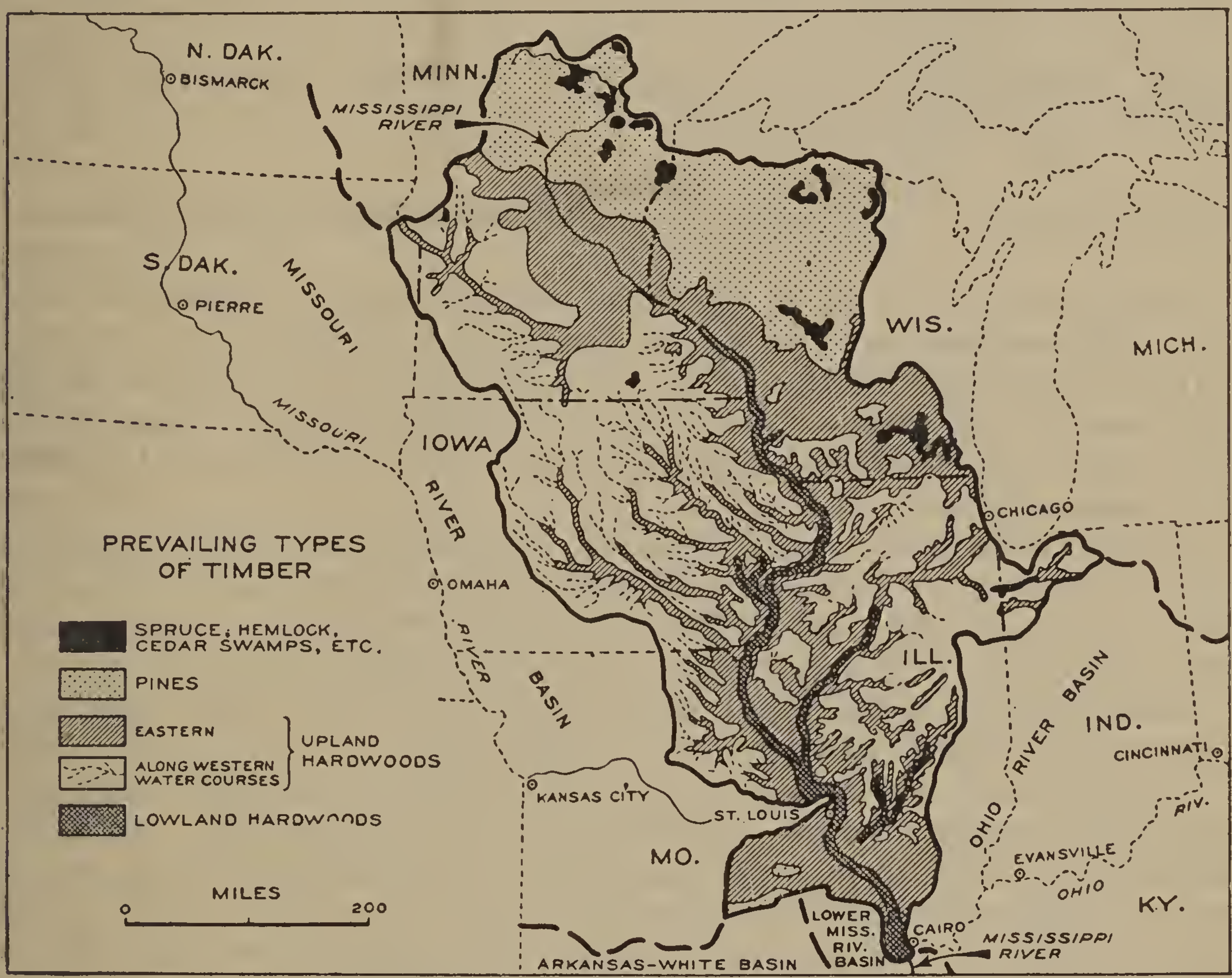

FIGURE 2.—Upper Mississippi River Basin

and, therefore, were mostly concerned with the total annual flow rather than the distribution of the flow during the season, and for this reason failed to observe some changes in the regimen of the river as the result of clearing and overgrazing.

With the general awakened interest in forest preservation and the establishment of State forest organizations in the region, new facts are coming to light as to the relation of forests to stream flow in the region. No attempt is made here to estimate the protective value of all the forests within the upper Mississippi Basin and evaluate their rôle in flood control in terms of second-feet of river discharge.

In any quantitative estimate of the protective value of the forest, one must have accurate data as to precipitation over the watershed, the annual discharge of the rivers, and what happens to the difference between precipitation and discharge in the form of transpiration, evaporation, and seepage.

Our rainfall records are far from accurate. In England, for instance, it was demonstrated that on a watershed of 49 square miles which has 42 weather stations, the readings from one station show a departure of 16 per cent from the mean; two stations, 11 per cent; and 14 stations, 2 per cent. In the United States we have only one weather station for 600 square miles; in Wisconsin, probably only one for 400 square miles.

Stream gaugings have been carried on only for a short time and show a great variation in the amount of discharge from year to year. There are practically no reliable records of evaporation from soils in the open and under forest. There are practically no records of amount of rainfall intercepted by crowns of trees in this country. There are considerable transpiration studies for cultivated plants but very few for forest trees.

The water balance in any locality in a humid region may be presented in the form of an equation:

$$\text{Precipitation} = \begin{matrix}\text{Water that reaches}\\ \text{the rivers}\end{matrix} + \text{Evaporation} + \text{Transpiration.}$$

Precipitation may be in the form of rain, snow, or hail, or in the form of condensation of vapor, such as dew, hoar frost, etc.

Water that reaches the rivers is made up of (1) surface run-off, (2) run-off from deeper layers of the soil, and (3) deep underground water that may reach the streams in the form of springs only after a long lapse of time.

Evaporation is the water lost (1) from water surfaces, such as lakes and rivers; (2) from surfaces of vegetation—this is the part that is intercepted by tree foliage and other vegetation and is evaporated back into the air; and (3) from the surface of the soil itself.

Transpiration is the water given off by the tree foliage and other vegetation as a part of their growth processes.

Precipitation varies from year to year and is modified only to a very slight degree by the conditions prevailing over the watershed. The amount of water that reaches the streams is affected by the topography of the watershed, by its geologic structure, by the soils, and by the character of the vegetative cover. The amount of evaporation, although more or less constant for water surfaces for a given watershed, varies greatly for land according to the character of the soil and the vegetative cover.

Transpiration within a given watershed is greatly affected by the character of the vegetation. The denser and the more vigorous the vegetation, the greater is the loss through transpiration.

The mean annual precipitation of the upper Mississippi Valley above the mouth of the Missouri River is about 415,000 second-feet. The mean annual run-off for the same watershed is 99,000 second-feet. There is thus an excess of 316,000 second-feet of precipitation over run-off. Unless we can show quantitatively how this difference between precipitation and run-off is distributed between evaporation from the soil, transpiration from grass, cultivated crops, and forest, and seepage under different vegetative cover, it is impossible to measure quantitatively the effect of forest in modifying the flood and low stages of our streams.

If, however, we can not yet give a quantitative expression to the forest influence, there is enough evidence to show that the forest cover has a decided effect on erosion from sloping land, on retarding surface run-off, increasing seepage, and reducing direct evaporation from the soil—all factors contributing toward making available more water for stream flow and at the same time flattening the crests of flood stages.

The forest and stream conditions for the major basins are given in Table 3.

TABLE 3.—*Forest and stream conditions of the upper Mississippi watershed by major drainage basins*

Major river basins	Drainage area, square miles	Forested	Cultivated	Grassland	Precipitation, second-feet per square mile	Run-off, second-feet per square mile [1]	Ratio of run-off to precipitation
		Per cent	*Per cent*	*Per cent*			*Per cent*
Mississippi above St. Paul	20, 449	56	32	12	1. 99	----------	----------
St. Croix	7, 664	69	21	10	2. 28	0. 73	32
Chippewa	9, 379	68	20	12	2. 43	. 90	37
Black	2, 920	55	28	17	2. 43	. 72	30
Wisconsin	11, 903	61	24	15	2. 43	. 86	35
Minnesota	16, 264	12	63	25	1. 99	. 47	24
Iowa and Cedar	12, 496	6	63	31	2. 36	. 59	25
Skunk	4, 323	9	62	29	2. 36	. 55	23
Des Moines	14, 184	6	64	30	2. 36	. 46	20
Rock	10, 765	12	57	31	2. 58	. 72	28
Illinois [2]	28, 244	8	73	19	2. 72	. 65	24
Kaskaskia	5, 812	11	82	7	2. 87	. 74	26
Big Muddy	2, 402	28	57	15	2. 95	. 77	26
Mississippi below St. Paul	40, 048	22	52	26	2. 50	----------	----------
Upper Mississippi watershed	186, 853	26	53	21	2. 22	. 53	24

[1] Run-off is the total amount of water available for streamflow, both from surface run-off and seepage.
[2] Including Kankakee and Des Plaines Rivers.

There is a consistent relationship between the proportion of forest within each watershed and the amount of water available for stream flow, as expressed by ratio between run-off and precipitation.

Since the stream gaugings are subject to great variations from year to year and records cover comparatively short periods, and since many other factors, such as configuration, topography of the watershed and soils, enter into this relationship, the relation is not advanced as proof that the more forested the watershed the more water is available for stream flow. The figures, however, are significant and are given for what they are worth.

CRITICAL AREAS

The entire forest area of 31,409,000 acres within the watershed may be considered as exerting directly or indirectly a beneficial effect not only upon the water balance of the upper Mississippi Valley but also upon its middle and lower portions.

Judging by the present economic trend and the trend of public sentiment, it is not likely that the existing forest area within the upper Mississippi watershed will be much further reduced by clearing, at least within the present generation. If anything, the forests, just

as in New England, may recover some of the lost ground. With the increasing value of the forest for the production of raw materials and recreation and with better fire protection and handling of the forests, much of the forest, at least in the sparsely settled portion of the northern watershed, will be maintained and its protective value increased without any need for its acquisition or control by the State or Federal Government.

There are, however, certain limited areas in the region the maintenance of which in forest can not be left to the chance that proper action will be taken by their owners, and there are also areas that need to be restored to forest. Critical conditions are found mostly on

FIGURE 3.—Upper Mississippi River Basin

land of dissected topography and readily erodible soils, on bluffs and bottom lands along watercourses, and on land of broken, rough topography at headwaters of streams. Such land when denuded of its forest cover becomes subject to rapid run-off, excessive erosion, caving in, with the result that the streams that drain it become subject to excessive rises. Once the erosive action has begun, it grows at an accelerated tempo and may lead to complete ruin of the surrounding agricultural land and the creation of torrent conditions.

All civilized countries of the world recognize such areas as being in need of special attention and special handling. These are the so-called protection areas and the forests upon them protection forests. Switzerland, France, Italy, Austria, Russia, Germany, Japan, Spain, and Portugal all recognize the importance of such protection forests and try to safeguard their maintenance by various means.

In determining the areas which need be kept under forest within the upper Mississippi watershed three considerations were taken account and, accordingly, three kinds of protection forests recognized—(1) areas of broken topography, subject to rapid surface run-off and erosion; (2) areas for stabilization of river banks and bottom lands; and (3) areas of broken topography at headwaters of streams. The location of these areas is shown on maps for major river basins and for the upper Mississippi watershed as a whole. Their approximate areas are given roughly in Table 4.

TABLE 4.—*Critical areas, by States*

States	Dissected land where run-off is rapid and erosion excessive	Areas for stabilization of river channels and bottom lands	Land of broken topography at headwaters of streams	Total critical areas
	Acres	*Acres*	*Acres*	*Acres*
Wisconsin	4, 976, 000	154, 000	1, 474, 000	6, 604, 000
Minnesota	2, 717, 000	231, 000		2, 948, 000
Illinois	1, 665, 000	535, 000		2, 200, 000
Iowa	2, 004, 000	123, 000		2, 127, 000
Missouri	2, 300, 000	134, 000		2, 434, 000
Michigan			22, 000	22, 000
Total	13, 662, 000	1, 177, 000	1, 496, 000	16, 335, 000

AREAS OF DISSECTED TOPOGRAPHY SUBJECT TO RAPID RUN-OFF AND EROSION

Areas of dissected topography subject to rapid run-off and erosion are found (1) on uplands, especially in the unglaciated sections of the watershed, and (2) on bluff land flanking the Mississippi River and most of its tributaries.

The most critical areas are those in the unglaciated sections of the watershed. The land within these sections is of such character as to permit rapid run-off and excessive erosion and is deeply dissected by ravines and streams. The streams are dry part of the year but rise quickly after heavy rains, and are very rapid. The flat uplands are in farms but the steep slopes are still largely wooded. The timber has been culled over. When the stands are open, there is grass. The wooded slopes are used for pasture and as a general rule are overgrazed. The ground is compact and is not in condition to absorb or retain large quantities of water.

The forest is in small farm wood lots which do not lend themselves to acquisition by States or Federal Government. Yet the importance of retaining the steep slopes of this dissected section under forest cover is very great. They are the areas which need attention first of all, as the conditions are becoming rapidly worse.

According to the Wisconsin Agricultural Experiment Station serious erosion is found on 75 per cent of the farms in this section. Erosion is also serious on land similar in character in the adjoining States of Minnesota, Iowa, and Illinois, bordering on the Mississippi River and its main tributaries. The conditions prevailing on this kind of land are detrimental to the surrounding agricultural land and to stream flow.

The eroded bluffs along the Mississippi River, and some of its main tributaries are also danger zones, whether they occur in the glaciated or unglaciated districts. The erosion is not so marked, however, in the glaciated districts as in those not glaciated. The bluffs facing the river are for the most part still wooded, but are being pastured and, where the forest is removed or where the ground is broken, they erode heavily. In some parts of the watershed as, for instance, in the southern part of Illinois along the Mississippi River, the forests form a continuous belt stretching for many miles along the bluffs. Though, for the most part, the woods are broken up, bodies of forest 10,000, 25,000, and 50,000 acres in extent are not rare. The wooded slopes of the bluffs lend themselves to public acquisition as they can be blocked out into practical administrative units.

With the same class of land belong several morainic hills of heavy clay soils in the northern part of the watershed and some uplands of broken topography for some distance from the river within the prairie section of the watershed. The critical areas of the above characteristics are found within a territory which may be roughly estimated for the entire upper Mississippi watershed at 13,662,000 acres in extent.

In Wisconsin the critical areas lie largely in the unglaciated region. These include the whole strip in the southwestern part of the State, from the mouth of the St. Croix River, west and southwest to the Illinois boundary a few miles west of Beloit. They embrace the lower portions of the drainage areas of the Chippewa, Black, and Wisconsin Rivers, the western portion of the drainage area of the Rock River, and almost all of the drainage areas of the smaller streams which flow directly into the Mississippi River below Prescott. The gross area, within which critical conditions are found, is some 4,976,000 acres. The extent and the seriousness of erosion are illustrated in Figs. 4 to 10.

In Minnesota such areas are found in the unglaciated southeastern portion of the State. They include Houston, Winona, Wabasha, Goodhue, and parts of Fillmore and Olmsted Counties. They embrace largely the drainage basins of the smaller streams flowing into the Mississippi. Outside of the unglaciated section, it includes the bluff land bordering the Minnesota River from Lac qui Parle to its mouth. The gross area embraces some 2,717,000 acres.

In Illinois the critical territory embraces the entire broken and dissected portion, which corresponds largely to the upland forested section of the State, amounting roughly to 1,665,000 acres.

Such dissected land, whether made up of soils readily erodible or resistant to erosion, gullies badly when deprived of vegetative cover. For this reason, practically all the wooded uplands and bluffs in the river basins of the Illinois, Kaskaskia, and Big Muddy lie within this critical area. This means that there should be no further clearing of the woods on such land. The clearing process has proceeded now as far as it can safely go. In some of the drainage basins in the State of Illinois over 75 per cent of the land is already under the plow. Aside from gullying, which is a common process of erosion, there is also a great deal of sheet erosion on land only mildly sloping. Often there is sheet erosion on sloping land which is not even subject to

gully erosion. On such sloping land the forest is the best protection against both sheet and gully erosion. For this reason, the clearing of forests on slopes with a gradient as small as 5 or 6 per cent should be avoided.

The extent of erosion that is actually taking place on land of this character, where the ground is broken by clearing or overgrazing, is shown in the accompanying photographs. (Figs. 11 to 17.)

In Iowa the area of dissected and eroded topography includes all the upland forests and the wooded slopes on the bluffs flanking the Mississippi River and such rivers as the Des Moines, Iowa, Cedar, and Skunk. The gross critical area corresponds closely to the upland forested area, amounting to 2,004,000 acres. (Figs. 18 to 20.)

In Missouri the critical area lies within the portion of the watershed tributary direct to the Mississippi and is confined to the dissected, erodible area and bluff lands along the Mississippi River and its tributaries. This area also corresponds to the upland forested area, including some 2,300,000 acres.

AREAS FOR STABILIZATION OF RIVER BANKS AND BOTTOM LANDS

Forests on the bottom lands of the Mississippi River and most of its tributaries resist the caving in of the banks, and thus make them more secure. They help in confining the water to the main channel. Furthermore, the bottom lands on the tributaries of the Mississippi, which have not been leveed to any large extent, may act as storage reservoirs and settling basins for the Mississippi River.

The best illustration of the action of forests in preventing caving in is found in Appendix P of the Report of the Chief of Engineers of the United States Army for 1881. By a series of four charts he illustrates the stability of wooded banks upon the Mississippi River between the Illinois and Ohio Rivers. On one chart is shown the shore line opposite the mouth of the Missouri as it was in 1870 and in 1879. In nine years the cave-ins at the upper end of this ground, where the bank was stocked with woods, were almost nothing; at the middle portion, the ground being cleared, there was an erosion of over 900 feet; and at the lower portion where woods are found again, there was only from 100 to 200 feet of erosion. Another chart shows a wooded bank on the Mississippi River just below Carroll's Island, as it was found in 1872 and in 1879. The wooded bank has been exposed to the attack of the main stream for seven years, and the erosion is nowhere greater than 200 feet, and in some places is less than 20 feet. On a third chart is shown a bank of the Mississippi River, alternately cleared and wooded, just above Kimmswick as it was found in 1873 and in 1879. Where the bank was cleared an erosion of 1,600 feet occurred in six years, and the river has been widened that much. The wooded point at the lower end has held on in a remarkable manner. On a fourth chart is shown Fishbank, where the erosion has been more rapid than at any other point covered in the survey. Nearly 2,000 feet have been washed away in the deepest part in the five years since 1874. The prominence of the patch of woods near the middle of the bend has resisted erosion.

O. H. Ernst, captain of Engineers, who makes the report, concludes with the following words:

> The facts, of which these are examples, lead to the belief not only that navigation has been deteriorating in the past but that the process is still going on and will increase in rapidity as further clearings are made, and that unless energetic methods are adopted to replace the guards established by nature and removed by man, the day will come when the navigability of the river for vessels that are now used will be destroyed.[1]

Where the river is leveed for nearly its entire length the effects of the roots of the trees in holding the banks of the river secure is of secondary importance, since the dependence is placed on the engineering works. But even then forest vegetation upon the levees themselves is an important factor against the action of the waves during high water. When the banks of the river and the channel itself are to be regulated by engineering works the major reliance, of course, should be placed on them, with such aid as engineers themselves wish to use in protecting the levees with trees and grass.

Bottom lands, however, along some of the tributaries of the Mississippi which have not yet been completely leveed, and will not be, such as the Kaskaskia, Big Muddy, Des Moines, and others, should be kept in forest. Although the Mississippi River during high floods may back up water into some of those tributaries, yet under ordinary conditions the forests on the bottom lands of the tributaries which are not leveed retard the delivery of the local flood waters into the Mississippi River and act as storage reservoirs. Furthermore, the slowing down of the current and the spreading out of the water over these wide bottom lands causes the sediment to settle and prevents it from getting into the main channels. These bottom lands, therefore, act not only as storage reservoirs but also as settling basins. Forested bottom lands slow down the current much more than if they are cleared. For all these reasons most of the bottom lands are classed as critical areas. The total critical area of bottom land is 1,177,000 acres.

BROKEN TOPOGRAPHY AT THE HEADWATERS OF STREAMS

In the northern portion of the watershed, especially in Wisconsin, there are several areas of rough morainic hills, which serve as divides for several important streams. The topography of these areas consists of a series of hills and kettle holes, with short slopes between, rarely exceeding 100 feet from top to bottom. Many of the kettle holes are poorly or not at all drained, so that water running down the slopes finds no channel at the bottom and either sinks into the ground or helps to maintain the existing lakes and swamps which are a characteristic feature within this area.

Some of these morainic hills are made up of lighter sandy and gravelly soils and are not subject to erosion. Others, however, have stony silt loam and are eroded when deprived of vegetative cover. The main function of these areas at the headwaters of streams is to act as storage reservoirs of the streams by preventing rapid surface run-off and in some cases also erosion. There are four such areas in

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[1] Executive documents, 3d sess., 46th Cong., 1880–81, Vol. IV. Report of the Chief of Engineers, Part II, p. 1370.

FIGURE 4.—Vertical sides of ravine cut down to bedrock. Buffalo County, western Wisconsin. Note men in right-hand gully

FIGURE 5.—Trees protect slopes from erosion, southwestern Wisconsin. Compare cleared and wooded portions of the slope

FIGURE 6.—Erosion following removal of timber and cultivation of a hillside in southwestern Wisconsin. Result of one season. (Courtesy of A. R. Whitson, University of Wisconsin)

FIGURE 7.—Sediment deposited by one flood in 1916. Buffalo County, western Wisconsin

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FIGURE 8.—Sediment deposited in a corn field after a single rainstorm. Wagon and cultivator left in the field night before rain almost buried. Buffalo County, western Wisconsin. (Two views)

104—5

FIGURE 9.—Grazing eliminates hardwood reproduction. Compare grazed woodlot (foreground) with ungrazed (background). Western Wisconsin. (Courtesy of A. R. Whitson, University of Wisconsin)

FIGURE 10.—Bowlders brought down during freshet in a side stream. Buffalo County, Wis.

FIGURE 11.—Erosion following removal of timber and grazing on light soils. Whiteside County, Ill. (Courtesy of C. J. Telford, Natural History Survey of Illinois)

FIGURE 12.—Effect of overgrazing in woodlots. Note contrast between undergrowth on the unpastured side of fence (background) and bare ground on pastured side (foreground). Lee County, Ill. (Courtesy of C. J. Telford, Natural History Survey of Illinois)

FIGURE 13.—Woods destroyed by excessive grazing. Grundy County, Ill. (Courtesy of C. J. Telford, Natural History Survey of Illinois)

FIGURE 14.—Gullying following removal of timber and cultivation of gently sloping land. Union County, Ill. (Courtesy of C. J. Telford, Natural History Survey of Illinois)

104—10

FIGURE 15.—Erosion following removal of timber in Carroll County, Ill. Gullies from 30 to 50 feet deep. Complete destruction of land. (Courtesy of C. J. Telford, Natural History Survey of Illinois)

FIGURE 16.—Erosion following removal of timber in Carroll County, Ill. Gullies from 30 to 50 feet deep. Complete destruction of the land. (Courtesy of C. J. Telford, Natural History Survey of Illinois)

FIGURE 17.—Erosion on wooded slopes as a result of overgrazing in bluffs bordering the Mississippi River in Whiteside County, Ill. View in bottom of gully. (Courtesy of C. J. Telford, Natural History Survey of Illinois)

FIGURE 18.—A peculiar straight "dissolving" type of erosion in western Iowa. (Courtesy of I. T. Bode, Iowa State College of Agriculture)

FIGURE 19.—Erosion on land only recently timbered. Lee County, near Keokuk, Iowa, on a tributary to the Mississippi. (Courtesy of I. T. Bode, Iowa State College of Agriculture, Ames, Iowa.) (Two views)

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FIGURE 20.—Land once timbered, then cleared, farmed until topsoil gone, and now being reforested. Jones County State Park, along the Wapsipinicon River, near Animosa, Iowa. (Courtesy of G. B. MacDonald)

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Wisconsin: (1) at the headwaters of the Wisconsin River in Vilas and Oneida Counties; the northwestern portion of this area also forms the headwaters of the Chippewa River; (2) an area between Prentice and Stanley, Wisconsin, which forms the divides between the Chippewa, Wisconsin, and Black Rivers; (3) an area northeast of Hayward on the divide between the Chippewa and St. Croix Rivers; and (4) a broken area south from Hayward to the northern edge of Chippewa County, forming a part of the divide between the Chippewa and St. Croix Rivers. The aggregate area of such land is 1,496,000 acres.

PROTECTION FORESTS

Within the areas classed as critical, the forest cover provides the needed protection to the land against erosion, and to streams against extreme and sudden fluctuations in flow. For this reason it should be retained there permanently. The forests on these critical areas are in a true sense protection forests. Since these forests, with the exception of northern Wisconsin and Minnesota, do not occur in large contiguous bodies but are largely in the nature of farm wood lots, or woodlands several thousand acres in extent, the exact location of each individual forest tract on the map of the scale adopted for this report is, of course, impossible. Moreover, while there are some individual tracts which may require especial attention, the measures for the maintenance and improvement of protection forests, as they will be discussed later, apply to all the forests within a given critical area. The aggregate area of protection forests in the entire upper Mississippi watershed is roughly placed at 9,354,000 acres.

In Tables 5 and 6 below is given for each major drainage basin and by States the approximate area of the different protection forests. These are discussed in greater detail in Appendix I, under individual river basins.

TABLE 5.—*Protection forests by major river basins*

Basins	Total forest area	Protection forests			
		Total	Against erosion	For stabilization of bottom land	For protection of head-waters
Mississippi above St. Paul	7,357,000				
St. Croix	3,384,000	297,000	258,000	18,000	21,000
Chippewa	4,091,000	592,000	75,000	10,000	507,000
Black	1,024,000	129,000	87,000	5,000	37,000
Wisconsin	4,630,000	1,790,000	941,000	10,000	839,000
Minnesota	1,246,000	74,000	51,000	23,000	
Iowa and Cedar	480,000	480,000	469,000	11,000	
Skunk	245,000	244,000	242,000	2,000	
Des Moines	545,000	545,000	535,000	12,000	
Rock	826,000	213,000	213,000		
Illinois [1]	1,367,000	321,000	221,000	100,000	
Kaskaskia	402,000	150,000	145,000	5,000	
Big Muddy	434,000	140,000	127,000	13,000	
Mississippi below St. Paul	5,378,000	4,379,000	3,977,000	400,000	
Upper Mississippi watershed	31,409,000	9,354,000	7,341,000	609,000	1,404,000

[1] Including Kankakee and Des Plaines Rivers.

OTHER FORESTS OF PROTECTIVE VALUE

In addition to the three types of protection forests described, the entire northern portion of Wisconsin and Minnesota, with its large areas of swamps and lakes, is properly considered a natural reservoir of the upper Mississippi watershed, and for this reason needs special consideration in connection with any plan for stream control. The importance of the forest cover on these sandy flats, interspersed with swamps and lakes, lies chiefly in reducing excessive evaporation from the soil and retarding the melting of snow in the spring. This is a region of heavy snowfall. This is also a region of coniferous forest, which is particularly effective in reducing evaporation and retarding the melting of snow.

The effect of the forests upon the melting of the snow is not merely in retarding its disappearance but in the disposal of the thaw water. The soil under forest is protected from loss of heat through radiation by the crown canopy, and, therefore, does not cool off as much as soil in the open. The leaf litter, which is a poor conductor of heat, also prevents the cooling of the soil and, like a blanket, protects it from freezing. The large accumulation of snow under the forest cover adds another protective cover to the soil. The chemical processes of decomposition, fermentation, and decay that take place in the leaf litter, are accompanied by giving off of heat. Thanks to this treble protection and the slow movement of the air, the forest soil either does not freeze at all in winter or freezes much later and to a much lesser depth than the soil in the open. In the spring, therefore, it thaws off early while the snow mantle is still on the ground. The forest soil, even on steep slopes with porous layer of leaf litter, acts as a sponge. It absorbs slowly the water resulting from the thawing of snow, and, when it becomes saturated, transmits the water to the deeper layers of the soil. As a general rule, the ground under forest, having been depleted by transpiration of the growing trees in summer, has a large storage capacity in winter and spring. Even if there is an excess of water, it runs off the surface only slowly, constantly being checked by the trunks of trees, by the innumerable ramifications of the roots of the trees, and the decaying remnants of trees. At every turn it has a chance to strike a spot which is not yet saturated with water, or to strike a hole of a chipmunk or other burrowing animal, and everywhere it soaks into the ground along the channels in the soil left by the decayed roots. By retarding the surface run-off of the thaw waters, by preventing the snow from being blown away, the forest accumulates a large amount of moisture in the soil which is used for feeding the ground waters.

What is more important, however, is the effect of the forest upon the movement of ground waters in winter. If the soil is not frozen or only slightly frozen, the movement of ground water continues normally throughout the winter, sustaining winter flow of rivers under the ice. If the soil is frozen, the movement of ground water in winter stops. The water accumulates in the soil, shallow streams freeze to the bottom, and there is a great drop of winter flow in the rivers. In the spring, the ground waters, which have accumulated

in the soil enter the stream in large quantities. Once in a while these ground waters break through in winter along the shore and appear above the ice in the stream.

These facts are of such common occurrence that local people know well of this particular function of the forest, and one needs to be blind to fail to see this great function of the forest as a regulator of water in the economy of nature.

A point on which hydraulic engineers are not fully agreed is concerning the value of swamps as regulators and feeders of streams. According to some hydraulic authorities, such as Prof. Daniel W. Mead and others, ponds, lakes, swamps, and marshes tend to regulate the flood flows from drainage areas and to retard the flow of storm waters, delivering them more slowly than would occur from other areas. The effect of lakes and swamps, in the opinion of these authorities, is to reduce the flood peaks and prolong the high-water period. In support of this, Professor Mead cites three rivers in the State of New York—the Hudson, Oswego, and Genesee. The Hudson River flows from a drainage area having numerous small morainic lakes, providing moderate storage. The Oswego has an unusual amount of storage in the numerous lakes of central New York. The Genesee has only a limited amount of surface storage. This difference in the storage facilities of the rivers is reflected in the flood discharge of the rivers. The maximum discharge in cubic second-feet per square mile for the Oswego, which has a large amount of lakes, is only 40; that for the Hudson, which has a moderate surface storage, is 100; and the Genesee, which has little or no surface storage, has a maximum discharge close to 220 cubic second-feet per square mile.

Another group of hydraulic engineers claim that swamps do not play an important part in the regulation of stream flow, neither at the time of flood nor at low stages. In the spring, when the excess of melting snow and the spring rains produce flood conditions, the storage capacity of the swamps is exhausted, and the excess water runs off from them as from a tin roof of a house. During the summer, at the time of low water, the Sphagnum moss in the swamp is so retentive of the moisture that it gives off moisture to the surrounding layers of soil with great difficulty and, therefore, does not add materially toward increasing the flow in midsummer. The evaporation from the moss cover, on the other hand, is very great with the result that most of the water in the swamp is lost in the air instead of being delivered to the streams. They further claim that these swamps, if they were drained, could be made to act as storage reservoirs, especially, if the ditches which drained them were provided with dams for the regulation of the outgoing water. So far, however, whatever drainage of swamps in the northern portion of the upper Mississippi watershed has been attempted was often ill advised, not prompted by any definite plan for water regulation, but for making land available for agriculture, in most cases far in advance of the actual needs. No control was provided for the outgoing waters from the swamps, and for this reason there is no question that many of the open drainage channels and ditches conduct

the surface flow from the swamps much more directly and quickly into the streams, and thus undoubtedly tend to increase the flood height in the spring without any compensating aid to the flow at the low stages. Furthermore, the drained peat swamps, because of their inflammable character and the difficulty with which fires can be put out, became a fire menace and in a few cases at least contribute to great forest conflagrations. For these reasons, no matter which point of view of the two opposing schools of hydraulic engineers is correct, no further unsystematic drainage of swamps is advisable. If such drainage is undertaken, it should be as a part of a comprehensive and definite plan for stream control and only after a careful study of the possible effect of such drainage.

The northern portion of the upper Mississippi watershed is, therefore, no matter how one looks upon the function of the swamps, either an actual or a potential storage area for the streams arising within the region. The effect of the removal of the forest within this upper portion of the watershed has not been followed, as a rule, by general denudation of the land. Second growth of one kind or another invariably comes up after cutting and even burning. The only possible effect is in changing the character of the forest. Instead of the original coniferous forest, a large portion of the area has now come up to aspen, birch, and similar hardwoods, whose protective value to the moisture in the soil is not as great as that of a coniferous forest.

Although the upper portion of the Mississippi watershed, abounding in swamps and lakes, is of great hydraulic consequence, the forests within it need not be classed at present as protection forests. First, to do so, it would be necessary to include almost the entire area of the original conifer, or mixed conifer and hardwood forest. Second, settlement is slow in this region, and within the last few years it has been either at a standstill or even reduced. Third, this region is of great importance for water-power development. Fourth, it is the great recreational region of the Middle West. Fifth, with the modified taxation upon cut-over land, there is a new incentive for the private owners to hold the land for timber growing. Sixth, this area is receiving increasingly better fire protection by the State and the private timber owners, and finally, a large portion of this area is in Government or State ownership. For all these reasons, it is safe to assume that this region will remain permanently in forest, that its condition will gradually improve, and the protective value of the forest be preserved without any special legislative or restrictive measures.

RECOMMENDATIONS

Of the 31,409,000 acres of forests within the upper Mississippi watershed, 9,354,000 acres, either by reason of their growing on steep, erodible slopes, or along river banks, or on rough land at headwaters of streams, must be classed as protection forests and be given special attention by the Government and the States in the development of their forest policies.

Table 6 gives the area of protection forests by States.

TABLE 6.—*Protection forests by States*

State	Total forest area	Protection forests			
		Total	Against erosion	For stabilization of bottom land	For protection of headwaters
	Acres	*Acres*	*Acres*	*Acres*	*Acres*
Wisconsin	13, 168, 000	3, 397, 000	1, 940, 000	75, 000	1, 382, 000
Minnesota	11, 143, 000	1, 039, 000	952, 000	87, 000	
Illinois	2, 200, 000	841, 000	661, 000	180, 000	
Iowa	2, 127, 000	2, 116, 000	1, 994, 000	122, 000	
Michigan	22, 000	22, 000			22, 000
Missouri	2, 434, 000	1, 939, 000	1, 794, 000	145, 000	
Indiana	304, 000				
South Dakota [1]	11, 000				
Upper Mississippi watershed	31, 409, 000	9, 354, 000	7, 341, 000	609, 000	1, 404, 000

[1] Including the Little Minnesota River Basin.

Specific measures for maintaining and improving the protection forests are discussed fully for each individual drainage basin. In a general way, the recommendations for the three kinds of protection forest are briefly these:

1. FORESTS ON STEEP SLOPES SUBJECT TO RAPID SURFACE RUN-OFF AND EROSION

Over a large portion of this area the forests are in the form of detached farm woodlots. This is especially true of Wisconsin, Minnesota, and some portions of Illinois and Iowa. They do not lend themselves to blocking up in practical administrative units, and, therefore, to acquisition by the State or Federal Government. In some of the drainage basins in Illinois and Iowa these forests, although in small ownership, are still in contiguous bodies, especially on the bluffs flanking the water courses. In the southeastern portion of Illinois contiguous bodies as large as 200,000 acres can be found, while in Iowa contiguous bodies of 5,000 and 10,000 acres exist. Where the forest is found in sufficiently large contiguous bodies, it is recommended that they should be blocked out and form purchase areas by the State or Federal Government. As a matter of fact, in the State of Illinois the purchase policy for State forests is to confine the acquisition just to this type of forest land. Where the forests are in the form of scattered farm woodlots, the counties and towns should be encouraged to establish county and town forests.

To encourage the farmer to maintain a good forest cover on these steep, erodible slopes and to keep his woodlot in good growing condition, planting stock, as provided under the Clark-McNary law, should be distributed on a liberal scale and the farmers encouraged to plant within their woodlots.

In such States as Minnesota and Wisconsin the forest taxation law should be amended so as to extend easement of taxation to such woodlot owners as are willing to eliminate grazing and clear cut-

ting in their woods. In Iowa such a provision is already in existence. In Wisconsin the new forest tax law includes woodlots but permits grazing.

The fire hazard is small and no special fire protection measures are necessary.

In order to encourage the farmer in maintaining the woodlot in good growing condition, better methods of wood utilization in connection with the existing wood-using industries should be taught.

Forest extension specialists should make an effort to demonstrate within such areas the evils of over-grazing and over-cutting which result in erosion.

Forest extension specialists should cooperate with the engineering departments of agricultural colleges in devising practicable means of stopping gullying by construction of simple dams, reforestation, or other measures.

Special attention should be given to preventing sheet erosion on gently sloping land by proper cover crops.

The contiguous bodies of forest can be acquired by the State or Federal Government for about $15 to $20 an acre for both land and timber. Because of the proximity to the prairie farming section such investment, aside from protection, can be made to pay in revenue from forest products.

2. AREAS FOR PROTECTION OF RIVER BANKS AND BOTTOM LANDS

Forests in bottom lands, where not drowned out by frequent flooding or whose protective value is not destroyed by levees, should at least in part be acquired in public ownership. The Federal Government is already making purchases of such lands from Lake Pepin south to Rock Island for the upper Mississippi wild life refuge. The Legislature of the State of Illinois recently passed an amendment, which still has to be voted upon by the people of the State, for the purchase of bottom lands for preservation of wild life and flood control. In Iowa there is a law according to which all bottom lands within the meander lines of streams are subject to public control. There is a tendency on the part of clubs and other organizations toward the purchase of forested bottom lands for game refuges and hunting grounds. Within the bottom lands of the Big Muddy Basin the mining industry is developed. The demand for mine timber is great and, therefore, the forests are a source of revenue to their owners. The utilization of these bottom-land forests is not inconsistent with their protective value.

The public acquisition of some of the forested bottoms and the economic and wild-life interests may, therefore, be depended upon to keep at least a part of these botton lands forested. The Engineer Corps of the United States Army, in connection with its river-improvement works, should acquire some of these forested bottoms where they fit in into their plans of river improvement.

The fire hazard is small, and no special fire-protection measures are necessary.

Forest extension among owners of these lands should be stressed.

3. FORESTS ON ROUGH LAND AT THE HEADWATERS OF STREAMS

These areas are contiguous bodies of forest and usually in large holdings. They have been almost entirely cut over and some of them burned. These lands are specially suited for public ownership, either by State or Federal Government. Both their protective and economic value is high. Their purchase value is low. It is the type of land which has been considered of a character that the State and the Government should own.

The fire hazard is great and needs well organized fire protection.

OTHER PROTECTIVE FORESTS

Within the northern portion of the upper Mississippi watershed, which forms a natural surface reservoir, there is no urgent need at present to acquire large bodies of forest, either by the State or Federal Government, for merely protective purposes. The area should be given intensive fire protection by the State in cooperation with the Federal Government.

The drainage of the swamps should be discontinued until a comprehensive plan for such drainage as a means of stream-flow control is devised. The economic and recreational interests may be depended upon to keep this region largely in forests.

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PART II

FOREST CONDITIONS WITHIN THE OHIO RIVER WATERSHED

By

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CONTENTS

PART II

FOREST CONDITIONS WITHIN THE OHIO RIVER WATERSHED

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INTRODUCTION

The Ohio Valley was once almost entirely forested. To-day only about one-third is forested. The main stream and its tributaries, which were once clear for a good part of the year, are now burdened with silt even at low stages. Land clearing has accelerated erosion in this region of heavy rainfall. Natural erosion channels have hastened the run-off and increased the height of flood crests. The valuable top soils are being washed from the fields of the valley itself, leaving the subsoil exposed; and the erosion and run-off are important contributing causes of floods on the lower Mississippi.

LOCATION AND AREA

The Ohio River watershed extends from the drainage system of the Great Lakes southward over the Appalachian plateau region and beyond to include the drainage northwest of the Blue Ridge in western Virginia, North Carolina, and Georgia. It has an area

of 203,782 square miles in 14 States. The Ohio River proper extends from the junction of the Monongahela and Allegheny Rivers, at an elevation of 703 feet, 965[1] miles to the Mississippi at Cairo, elevation of 273[1] feet. Tributary to the Ohio River are 17 rivers of major importance, besides several shorter rivers and numerous creeks which flow directly into it. The area in each State drained by each tributary is shown in Table 1, page 693.

TOPOGRAPHY

The Ohio basin is roughly triangular, high and mountainous in its eastern and southeastern sections and comparatively low and rolling along the northerly and westerly boundaries. The eastern part of the basin lies in the Appalachian plateau, which, at its northern extremity in the headwaters of the Allegheny River, reaches an elevation of about 2,000 feet. The height of this plateau increases to the southward, reaching an elevation of about 4,000 feet in West Virginia. The southern part of the basin is in the Cumberland plateau, a part of the Appalachian plateau. The Cumberland plateau is 3,000 feet high in Kentucky, becoming gradually lower toward its southern extremity in northern Alabama where it has an elevation of about 1,500 feet. The highest elevation on the drainage basin is in western North Carolina and along the boundary of eastern Tennessee, where several of the mountain peaks are more than 6,000 feet high. The southeastern rim of the basin from the vicinity of Roanoke, Va., to southeastern Tennessee is terminated in the Blue Ridge, which has a general elevation of nearly 4,000 feet.

The mountainous section includes three distinct areas; the rugged ranges of the older Appalachians east of the Appalachian valley, the long ridges in the Appalachian valley, and the deep dissected high Appalachian plateau. The first group is made up of the Blue Ridge, Smoky, and Unaka Mountains, with irregular intervening cross ranges. These mountains are steep with narrow valleys. The mountain ranges of the Appalachian valley are largely in the Tennessee drainage. They are folded frontal ranges of the Cumberland plateau with comparatively broad valleys between them. The Appalachian plateau, which was elevated to about 4,000 feet at its highest point, has been deeply dissected by streams, so that it now has a truly mountainous topography through central Tennessee, western Kentucky, and eastern West Virginia. The valleys are narrow with very limited flood plains along the streams.

Two parts of the Appalachian plateau are recognized—the Allegheny plateau north of the Kanawha River and the Cumberland plateau to the south. West of the higher plateau is a region of rugged hills occupying the western half of West Virginia, the southeastern part of Ohio, and a strip through the highland rim section of Tennessee. Additional areas with rugged hilly relief are found in the Ohio drainage in the Knobs and western coal-field sections of Kentucky, the unglaciated section of Indiana, the Ozark region of Illinois, and the bluffs along the main streams. In all of these sections land clearing has been extended to slopes which soon eroded severely. Many of the fields on these slopes have been abandoned.

[1] Rept. Pittsburgh Flood Commission (low-water elevation).

Rolling land and low hills are found within the region covered by the Wisconsin glaciation, to a less degree in the exposed areas of Illinoian glaciation, in some of the limestone plateaus of Kentucky and Tennessee, and in parts of the Appalachian Valley.

Flat land is limited to the flood plains of the larger streams, chiefly in the lower end of the Ohio Valley, and to a few areas where shallow glacial lakes once existed. Most of this flat land has been drained for agricultural use and is now in crops.

The striking characteristic of the Ohio drainage system is the almost complete absence of natural swamps and lakes to serve as storage basins. The drainage of this entire system has been well established through ages of weathering, which in some instances has worn away several thousand feet from the former surface. Even the comparatively recent encroachment of the glacier into the northern part of the basin has left very little interrupted drainage, since the streams reestablished themselves as the ice sheet withdrew. The swamp lands of the valley are almost entirely the flood plains along the streams and these are poorly drained during only a part of the year. In the drainage basins of the Allegheny and Beaver Rivers some small swamp areas are found, and through the western and central parts of Ohio are areas of flat land. When this was forested, it was swampy in character and supported a type of forest suited to wet land. Since it has been cleared and in part drained, it can no longer be called swampy.

Topography is the predominating element in determining the use of land in the Ohio basin. The mountainous sections are generally too rough for cultivation and have only a small percentage of land suited to agricultural use. Much of the hill land is too steep to permit efficient use of farm implements. Only in about half of the basin—the western and northern sections—is the topography suited primarily to agricultural-crop production. Even here some hill lands and some bluff lands along the drainage channels are too rough for cultivation.

It must be recognized that the present topography has been established by erosion and can be retained only by adequate surface-soil covering, or by preventing erosion and the removal of the valuable surface soil through proper methods of cultivation and use. Clearing the land of its timber cover has started a new active stage of erosion.

GEOLOGY AND SOILS

A large part of the present surface of the Ohio basin is closely associated with the weathering of the rock formations of the Carboniferous period, during the latter part of which the upper strata of the Appalachian plateau were laid down. The plateau province with its western extension in Kentucky, Illinois, and Indiana comprises more than a third of the entire basin. Surface formations were derived partly from heavy marine sediments accumulated throughout periods when the region was covered by sea, and partly from gravels and sands washed from the ancient continental areas.

The sediment deposits were laid down at first in horizontal layers, but subsequent movements of the earth's surface brought about two principal deformations. In one case the newer Appalachian Moun-

tains were developed by a somewhat regular folding of the stratified layers. In the other case an immense area was broadly uplifted to form the Appalachian Plateau.

This broad plateau, which once extended northwestward over the Ohio Valley, was distorted by an upward bending of the strata to form an anticline whose top lay along the line from the present location of Nashville, Tenn., to that of Cincinnati, Ohio. Erosion in the center of this plateau was more rapid than on its edges, and resulted in the exposure of the deep underlying strata of older rock. This peneplained plateau was then slowly elevated and eroded to its present condition.

In general, where folding occurred, the force was directed westward so that the folds are more compressed or steeper on the eastern than on the western side. This expresses itself in many ways in the present topography of the country.

The western boundary of the Appalachian Plateau is irregular as a result of erosion by the streams that cut into its margin. A few areas of the plateau may be somewhat even, as in the lower Cumberland Plateau, but elsewhere it has a rough mountainous topography of deep-cut narrow stream valleys and sharp ridges.

In a part of northwestern Kentucky and in parts of southwest Indiana and southern Illinois the country rock is of the same geological period as that underlying the higher Appalachian Plateau. The shales and sandstone, however, are in general of finer texture and not as resistant to weathering as that of the eastern plateau. This region is known as the Western Coal Fields of Kentucky. It has not been elevated, and in Kentucky it has been partly covered with recent alluvium. A part of it has poor drainage and is subject to overflow during flood stages in the Ohio.

The great geoanticlines (Nashville and Cincinnati domes) served to expose the central area of the Ohio Basin to more active erosion. The result has been the almost complete removal of the Upper Carboniferous formations of this region and the exposure of the underlying rocks of the Lower Carboniferous or still older periods.

The bluegrass region is the result of the unroofing of the Cincinnati geoanticline covering parts of Ohio, Indiana, and Kentucky; and the exposure of the highly phosphatic Ordovician limestones. The region in Kentucky is divided into an outer and inner basin. The latter has resulted from the wearing away of the limestone formation that underlies the outer region and the exposing of a still purer granular crystalline limestone beneath. A formation of shales between these two gives rise to the poorer hilly zone.

The Central Basin of Tennessee has resulted from the wearing away of the upper formation of the Nashville geoanticline, and the exposure of a formation of the Ordovician limestone. This limestone has weathered to a base level 300 to 400 feet below the surrounding country.

The exposure of the tilted formations that once covered the dome of the Central Basin has produced an escarpment completely encircling the basin. This is known as the Highland Rim. The exposed formations are shales, sandstones, and limestones from Silurian, Devonian, and lower Mississippian periods. The true topography of the country is that of a highland plain, strongly

weathered into steeply round hills at the edge of the Central Basin. The resistant Mississippian limestone is the chief cause of the escarpment.

Most of central Tennessee and Kentucky outside of the bluegrass region and the escarpment of the Central Basin is underlain with limestones, shale, and sandstone formations of the lower Carboniferous (Mississippian) period. Two important systems, are recognized. The older is the lower Mississippian, which includes such groups as the Waverly, the Fort Wayne, and the Tullahoma. Cherty and impure limestone, sandstone, and shales make up the principal rock structures. These weather badly and often give rise to irregular topographic features such as the Knobs and Barrens of Kentucky, the Knobstone section of Indiana, etc.

The younger, upper Mississippian system, includes the Chester and St. Louis groups, made up of limestone, calcareous shales, and sandstone. The weathering of these groups has given rise to a characteristic rolling topography. Sink holes and caves are commonly present.

The narrow belt between the Tennessee River and the recent loess and alluvium deposits bordering the Mississippi is underlain by an Upper Cretaceous formation of more or less unconsolidated sands and clays. Calcareous deposits and lignite also may be present. It is geologically a part of the southern coastal plain.

The Appalachian Valley traverses the Ohio Basin in eastern Tennessee and western Virginia. The valley as a whole has been evolved by the weathering of sharply folded strata. The present topography is formed of several long narrow valleys separated by parallel ridges. The valleys are underlain with limestone, the weathering of which has resulted in the characteristic rolling topography.

Only a small portion of the Ohio River Basin (Tennessee east to the Great Valley, western North Carolina, and a part of western Virginia) lies within the older Appalachian Mountain belt. The rock structure of this older mountain belt is chiefly granite, gneiss, and schist. The Blue Ridge Mountains are in this region.

West of the mountains of crystalline rock structure and east of the Appalachian Valley there lies a narrow belt from younger metamorphic rocks—quartzites, quartzite conglomerates, sandstone, shales, and slates. These characterize the Unaka Mountains.

Glaciation is responsible for the physiographic character of the northern belt of the Ohio Basin.

The soil series of the Appalachian Plateau are derived largely from the weathering of sandstone and shale of the Upper Carboniferous period (Pennsylvania system). The relative proportions of sandstone and shale determine the general texture of the resulting soil. The early rock groups of the Pennsylvanian system are chiefly coarse sandstones and where these constitute the summit and ridge formations the residual soil is sandy in texture. Most of the published soil reports of the United States soil survey have listed the De Kalb soil series as the predominant series from these sandstone formations. The weathering of these coarse sandstone formations proceeds slowly and erosion tends to remove the soil almost as rapidly as it is formed, hence the resulting soils are shallow. Where shales are abundant and the sandstones are absent or are of fine-

grained structure, the resulting soils are heavier or more clayey in texture.

Soils textured like those of the uplands of the Appalachian Plateau would show little erosion on a more level topography because of their porous nature. The fact that they are usually thin and that they are exposed on very steep slopes without adequate vegetative cover accounts for the prevalent washing.

The soils within the valleys and lower slopes throughout the plateau region are largely derived from wash from the uplands. They are often silty and sometimes of medium depth. They are fairly porous and show good underdrainage as a rule.

The inter-plateau region of southeastern Ohio and western West Virginia is underlain with shale and thin limestone formations of the Permian and Upper Pennsylvanian systems. The soils derived from these formations are chiefly clay loam or loam types. Soil types of the Meigs series predominate. These are derived from the weathering of red shales and sandstone. Where limestone is present they are considered good agricultural soils and are cultivated wherever the topography permits. Although they possess a fair underdrainage as a rule, they are nevertheless subject to considerable surface washing and gullying on slopes. On steep topography they are subject to landslides and slips.

The southern limit of the Wisconsin drift marks the boundary of the heavily glaciated area. The soils of this area have been derived from the weathering of the upper surface of glacial till. Although the drift itself may be 200 or more feet in depth, weathering has proceeded only a few feet. The condition under which this weathering has taken place determines the character of the resulting soils. As a rule the soils developed under swampy conditions are the heavier and darker, and contain the greater proportion of organic matter. Glacial lake soils are common. These are often heavy and close textured because of the finer particles washed in from surrounding regions. Old beach lines of gravel and sand are also common.

These heavily glaciated regions are level to rolling in topography and many of them are artificially drained for agricultural use. Erosion is not a serious problem, although on slopes and bluffs along streams washing and gullying may sometimes occur.

From the southern boundary of the Wisconsin drift the Illinoian drift has extended the glaciated region southward. The glacial drift of this region is shallower than the Wisconsin drift. and its surface is partly made up of finer material transported by wind and water. Because of this fact the soils may be of a more homogeneous silty nature. and because of their texture are more subject to erosion. Furthermore, the topography of this area is much rougher and this renders the soils sometimes subject to destructive washing when exposed. For the above reasons the area covered by the Illinoian drift has been placed in the same soil province with the alluvium and loess soil areas bordering the Ohio River westward from central Ohio. The soils derived from the cretaceous formations of western Tennessee are placed in this same province because of their susceptibility to erosion.

The soils of the limestone uplands have been derived from formations of different geological periods. Some. notably those of the cen-

tral basin of Tennessee and the blue-grass region of Kentucky, are the valuable agricultural soils, occurring over a rolling limestone topography. The underdrainage is usually good, partly through sinkholes and caverns. The most common soil types are silt loams and silty clay loams of medium depth. When these soils are injudiciously cultivated on slopes and when the organic matter within them becomes low they are readily washed. Other soils, as in a portion of the Highland rim region and the Barrens and the Knoblands of Kentucky, are relatively thin and stony, and, as they often occur on a relatively rough, broken topography, they are not considered of high value.

The principal soils of the Appalachian Valley wash considerably when injudiciously cultivated. The soils of the narrow parallel ridges within the valley are thin and often stony and may wash badly.

The soils in many parts of eastern West Virginia are calcareous. For this reason they develop grass cover readily when cleared or exposed, even on comparatively steep slopes. The Unaka Mountains are of quartzite, slate, shales, and sandstone. The soils from the quartzite and sandstone are often of sandy texture and may be comparatively shallow. The slate and shales have weathered into deeper clayey soils, which have a rapid surface run-off and on slopes tend to gully.

The Blue Ridge Mountains are of granite, gneiss, and schists, which weather to form sandy or light-textured soils. These are usually on the upland slopes and at higher elevations. They are not particularly subject to washing because of their structure, but because of their position they suffer from washing when cleared.

At lower elevation the micaceous schists have given rise to clayey soils. These may be relatively deep. Their heavy texture causes rapid surface run-off and renders them particularly susceptible to heavy erosion.

CLIMATE

Precipitation in the Ohio Valley region has its source largely in the southern Atlantic Ocean and Gulf of Mexico. The winds from the east and southeast provide the moisture to the cyclonic storms which sweep across the region.

The Ohio Basin lies directly in the most frequented path of storms of the continent. Those originating in the North Pacific, even if they enter the United States across the region of Montana, commonly pass southeasterly and out across the Ohio Valley or Lakes district. Those entering by way of Texas usually pass in a northeasterly direction across the Ohio Valley. Even those storms which enter the United States from the western Gulf section and pass southeast of the Appalachian Mountains bring a certain amount of precipitation to the northern section of this basin. To understand well the climate of the Ohio Basin, it is necessary to conceive of this as being the converging point for the widely distributed storms passing eastward across the continent and to realize that as these storms approach the east coast they are fed by moist winds blowing in from the Gulf and ocean areas to the southeast.

Since the moist air is fed into these storm centers largely from the south and east, precipitation may be expected to decrease from the

east side of the Ohio Basin westward. This is actually the case. The highest mean annual precipitation, about 70 inches, is in the extreme southeastern portion of the basin on those mountains which intercept storms from both Gulf and Atlantic sources.

Storms of extratropical origin are less common in the winter, so that in general a dry period is experienced in the southern mountain section during the fall, winter, and early spring. The summer in this section is the time of higher precipitation.

The lowest precipitation for the basin is in the extreme northwestern part where it reaches a mean for the year of about 36 inches. The condition of dryness in this northwestern section is created not only by the remoteness of large ocean bodies but by the interference of the high eastern mountain rim. The precipitation in the southwestern section is high, averaging about 66 inches. Also this section of the basin is so located that it may be subjected to very heavy precipitation in a short period of time. During the months of March and April, 1927, the precipitation for the section of the basin about the junction of the States of Mississippi, Tennessee, and Alabama reached 25 inches.

Precipitation in the northern part of the Ohio Valley is influenced by the general course of winter storms which pass across it from the region of Montana after passing through the Missouri Valley.

The course of storms across the Ohio Valley has an influence upon the temperatures which accompany their passage. The more southerly the course of these storms the greater the tendency of the temperature to drop following their passage.

The broad north and south extent of this valley creates also a considerable difference in mean annual temperature, which influences the amount of snowfall and the extent of freezing of the ground. The northerly part is subject to rather severe freezing and considerable snowfall, but in the southerly part the accumulation of snow exerts a minor influence on the extent of spring floods. The northeastern section is subject to rather heavy snowfall, while the northwestern part, because of decreased precipitation, and in spite of its lower temperatures, does not accumulate a material amount of snow. As the direct result of these conditions, flood waters in the southern part of the Ohio Basin come largely from heavy and continued rains, while flood waters in the northeastern section of the valley may rise in the spring very largely from sudden thaws. The accumulation of ice in the streams is only important in the extreme northeastern part of the valley. Severe local storms, commonly known as "cloudbursts," are more commonly found in the mountain and plateau sections in the southeastern part of the valley, where the accumulation of moist warm air from the southeast can be most easily brought in contact with colder air from the interior basin.

HISTORICAL DEVELOPMENT

The first settlement of the Ohio Valley took place along its northern border, during the occupation by the French. The general settlement which resulted in the destruction of the great hardwood forest and the clearing of the land for agricultural use began after the American Revolution.

When the great hardwood forest on the continent was cleared, overproduction, poor markets, and a class of hardwood timber ill suited for general construction prevented the use of millions of feet of good-grade material. The woodland incorporated within the farms was cut over without thought for its future; the best trees and best species were taken out, and the inferior members of the stand were left. The prevalent practices of burning and of grazing the farm woodlands destroyed the crop of young trees and brought these remnants of the old forest to their present ragged and depleted condition.

The outstanding fact in the story of the Ohio Basin is that the stage of exploitation of natural resources still persists. Coal, oil, and timber have been and are still being exploited without regard for future needs. On agricultural lands a certain measure of crop rotation is practiced to conserve the quality of the soil, but little has been done to prevent serious and constant loss through erosion on cropped land. The fields on steep slopes, when so eroded as to make further cultivation impracticable, are abandoned or seeded down to grass for pasturage.

The Ohio Basin is primarily agricultural in character because of its topography and soils and by virtue of its location, including as it does the center of population of the United States. While there can be no logical argument for the restoration of this agricultural land to a forested condition, the fact must be faced that the removal of the forest, the construction of drainage ditches, the straightening of streams, and the loss of protective cover of the soil have exerted a tremendous detrimental effect on the run-off of the basin. This is especially true of that portion of the drainage north of the Ohio River, where the high, generally flat plateau lands of central Indiana and Ohio were formerly poorly drained and held water on their surface much longer during each season than at the present time.

In the rough mountain lands in the eastern and southeastern part of the basin, clearing of land for agriculture has progressed beyond the point where it can be economically justified. During the period of early settlement the clearing of small mountain fields was common practice throughout the rougher portion of the basin. At that time it was possibly justified by the modest money requirement of the people for purchases in the open market. With the development of transportation, increase in population, the opening of factories, and expansion of public enterprise, financial requirements have increased. The earning capacity of mountain farms has not been able to maintain the pace, and the value of the produce has reached a low scale in competition with produce raised in more favored localities. As a result, mountain farms have been abandoned, and the tendency to abandon such land is increasing rather than diminishing, chiefly because of the development of motor transportation and the readiness with which employment can be obtained within reach of the most remote mountain settlement. The investment in such farm lands has been largely one of labor, since the money investment in buildings and other improvements has been small. There is, therefore, very little inducement to the people to continue the type of living to which they were accustomed three or four decades ago.

The history of the rougher land unsuited to agricultural development has been influenced by several factors. Large areas have been

acquired by large corporations and held for their mineral values. Similarly some areas have been purchased by lumber companies purely for the merchantable timber there standing. In practically all cases where land has been held in large blocks, the owners have been forced to market the timber as soon as it has become merchantable in order to pay the carrying charges. In practically all logging operations, fluctuating market values have caused variations in the closeness of timber utilization. At first, the more readily accessible portions were cut over only for the best saw timber, but this land and most of the remainder have now been cut for lower-grade material. Besides lumber, material taken out included ties, telephone poles, cooperage stock, posts, pulpwood, and tanning extract wood. Where the markets were especially good, the cutting was very close. The early development of the iron industry caused the clear cutting of hardwood timber for charcoal production. Wherever such land was not subsequently cultivated and was protected from fire and grazing, excellent stands of second growth hardwood have come in.

CONDITION OF NONFOREST LAND

From the bluegrass region of Kentucky northwestward, the land in the Ohio drainage is largely utilized for the production of cereal grain crops and livestock. The development of dairying and stock production combined with rotation of farm crops primarily for corn production (an intensive form of agriculture) seems to be maintaining itself effectively on the more level and rolling lands. Only along bluffs adjoining the stream courses and in the hill and mountain sections has erosion of farm land progressed far enough to cause abandonment of the fields. The agriculture census of 1925 shows the following condition in the Ohio Valley region:

Total land acreage	Area in square miles	Per cent of total
Land in farms	149, 429	73. 3
Land in crops	63, 454	31. 1
Land in pasture	50, 360	24. 7
Land in forest	68, 223	33. 5
Land in pastured wood lots	11, 474	5. 6

The area of rough land in crops is decreasing because of the introduction of heavy farm machinery, the increase in cost of labor, the competition of richer and more level lands in the production of agricultural crops, and the deterioration of the hill lands through continuous cropping and erosion. Furthermore, industrialism is on the increase.

During the earlier history of the mountain sections, a rather poor grade of stock, both hogs and cattle, was run at large over the unfenced mountain lands. Laws were passed requiring the fencing of agricultural crops and thereby recognizing the right to range stock at large. In most States these laws were subsequently repealed and other laws passed requiring the fencing of stock. The inclosure of stock in fenced pastures and the improvement in the grade of cattle have made poor pasturage on the open range less desirable. In

consequence of this, unfenced lands which were originally pastures have been allowed to grow up to brush and ultimately to forests. This in turn has had a favorable reaction upon the burning of the woods which was formerly practiced by nonowners on the wild forest range. Although the practice of burning of forests exists still in some sections of the mountains, it is being gradually overcome through education of the people to an appreciation of the damage done.

The tendency during the last several decades to abandon steep hill and mountain fields has without doubt saved much of this land from more severe erosion. It would be difficult to conceive the rapidity and extent of erosion on these lands when devoid of cover but for instances such as the area denuded by smelter gas near Ducktown, Tenn. This area lost not only its cover of trees but also of grass and is now deeply gullied. A less severe instance is found in the denudation by coke-oven gasses in western Pennsylvania.

Pastures, as a rule, do not erode after a sod is once established, except where the grazing of cattle establishes water courses or too heavy grazing during wet seasons tends to destroy the grass cover. The steep hill pastures develop bare spots caused by sheet erosion of the finer soils. Where the soils are coarse, these pastures are eventually occupied by weeds, brush, and trees.

Some improvement in worn-out pastures on sand and shale soils can be made by treatment with lime and phosphoric acid, which increases the density of blue grass after a clover seeding. Unless such a practice is adopted and proves economical, pasture on steep hillsides will eventually erode to a condition of low production and must be allowed to revert to forest.

CONDITION OF THE FORESTS

The forest of the Ohio Basin is almost entirely composed of upland hardwoods except for small areas of spruce and hemlock in the mountain section of West Virginia, North Carolina, and Tennessee and a small amount of swamp hardwood type on the alluvial lands along the stream bottoms. The bulk of the swamp-type land is concentrated in western Kentucky and southern Illinois. Northern white pine now occurs only sparsely mixed with other species in the eastern part of the valley. Shortleaf pine, pitch pine, Virginia pine, and mountain pine, the common yellow pines of the mountain region, are usually found mixed with hardwoods on the dry slopes, especially in the mountain and plateau region south of the Ohio River. The area occupied by these species is included in the upland hardwood type.

The forest of the Ohio Basin may be again subdivided according to its character into three divisions: 1. The comparatively contiguous bodies of timber found in the rougher parts of the mountains and plateau. 2. The farm woodlands which are isolated small bodies of open timber scattered through the better agricultural sections. 3. The fringe of hardwood species generally found along the stream courses on the bluffs and banks of the streams.

The greater part of the mountain and plateau timber lands has been culled for the best timber, and on much of the area a record

cutting has taken a lower grade of product. Cutting of all degrees of severity can be found in the mountain and plateau forests, depending upon the kind of material removed. Thus an almost complete destruction of the original cover results where cordwood is cut for destructive distillation, pulp wood, or chestnut acid wood. Where saw timber alone is cut, a large number of trees of poor species or those defective because of injury by fire or other agencies are left. This cull stand is usually open and incapable of completely occupying the soils. Clear cutting for charcoal production is preferable to the more extensive cuttings solely for the better grade saw timber; after clear-cutting sprout and seedling growth reestablishes itself. The entire stand established by both methods of cutting is in serious need of cleaning to remove the defective and

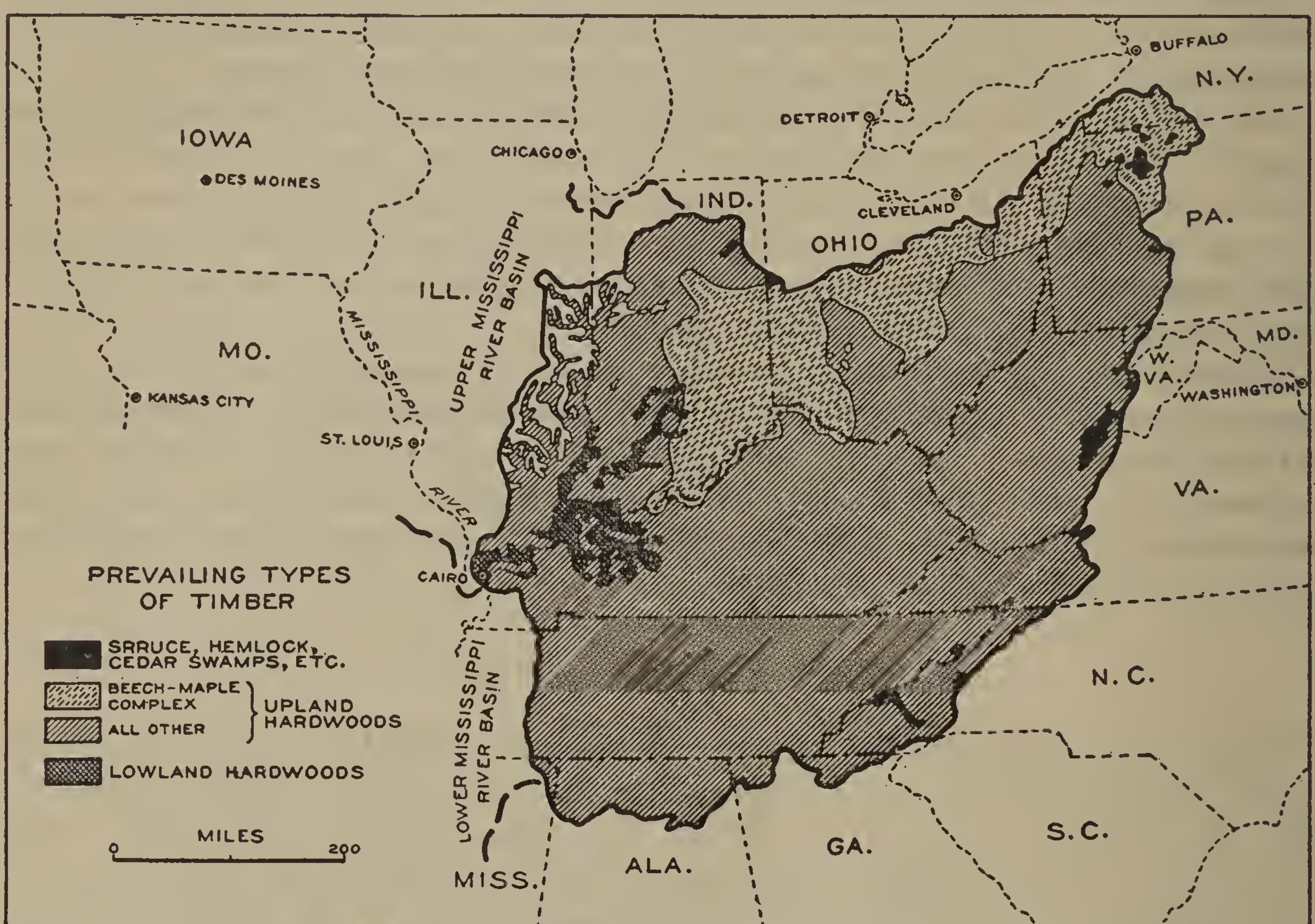

FIGURE 1.—Ohio River Basin

low-grade material and to give the young growth a better opportunity to mature.

Since the hardwood forest each year sheds its leaf crop, a hardwood litter and humus continually covers the ground. By the late summer season this has disintegrated, and, except in the dense woods, little of it remains through a second year. However, because of the present thin character of the forest cover and the excessive injury by fires, the maximum amount of leaf litter exists over a very small portion of the upland hardwood forest floor. Increasing the density of the stand and protection from fires will materially build up this forest humus.

Cattle browsing in fenced wood lots commonly results in opening up the underwood, thereby subjecting the stands to the sweep of the wind. Part of the leaf litter is blown away. Wind and exposure to sun and weather cause the quick disintegration of the remainder. Farm wood lots have little leaf litter beneath them, and in some

instances in which grazing has been carried on for a long period the stand becomes open and parklike, with practically no litter on the ground but with a grass cover beneath the trees. To correct this condition the stock should be removed and a wind mantle of undergrowth should be allowed to establish itself along the edge of the wood lot.

The fringes of woodland along stream courses, while of minor importance as wood-producing properties, may be very important in safeguarding valuable bottom lands by helping to stabilize the stream channels through binding the soil on the banks and flood plains. This prevents the shifting of the channels, with resulting injury to fertile lands in the flood plains and increased burden of flood-borne silt.

Such woodland along stream courses also interferes with the flow of water after the stream has spread over the flood plain, thereby increasing the time required for the water to drain out of the flooded area. This retardation of run-off is desirable as a general flood-prevention factor. Obviously, the longer the period required for run-off the more the flood crest flattens out. Such temporary storage on an individual drainage may be either an advantage or a disadvantage, depending upon special conditions. The removal of the forest cover in order to relieve the local trouble by speeding up the flood waters is usually a dangerous expedient, since such a local remedy may increase the hazard lower on the stream. The removal of the forest for local flood control should be tried only as a last resort and should be limited to the smallest amount affording reasonable relief.

PROTECTIVE VALUE OF THE WATERSHED

The Ohio watershed has a well-established drainage over all its surface except a small amount of flat land at its western end. It receives a heavier precipitation than any other main tributary of the Mississippi. The headwaters of all streams are in mountainous or hilly country and the gradients of the tributaries increase toward the sources. Briefly, the Ohio watershed has been physiographically formed and located to create floods in its lower reaches. Because it was located in a region of sufficient rainfall and had a good soil it was forest covered at the time of settlement. Clearing of two-thirds of its forest and cultivation of its soils have increased the rate of both run-off and erosion in periods of heavy rainfall.

Soils.—In rating the protective value of soils, depth, porosity, and resistance to erosion must be considered. The soils of the Wisconsin drift through the northern part of the watershed are deep and comparatively porous. Sandy soils of the Cumberland plateau though often shallow are very porous and do not readily erode. The soils of the upland limestone region of central Kentucky and Tennessee have good under drainage. The micaceous clay soils of the Appalachian Mountains and the limestone areas of eastern West Virginia and the Tennessee Valley though compact are subject to gullying. The soils which wash most easily include that of cretaceous origin in western Tennessee, the alluvium and loess soils along the main Ohio River, and the wind blown and silt deposits of the Illinoian drift scattered through southern Illinois, Indiana, and Ohio.

Precipitation.—The highest precipitation occurs in the extreme southeastern part of the basin, and is generally high over the southern and eastern rim. Through the mountain section in the southeast sudden and severe storms are likely to occur. In the extreme northeastern section, and only there, the accumulated snow is an important factor in spring floods. The severity of precipitation generally decreases northward and westward across the Ohio Valley, reaching its lowest point in the prairie region of northwestern Indiana. None of this area should, however, be rated as high as 100, since the precipitation is 35 inches or more in all sections of the valley.

All portions of the Ohio Valley region are subject to severe and comparatively heavy thunderstorms. Rains lasting 48 hours or more may occur in any part of the valley. Such a storm as this caused the flood at Dayton in 1913, and the unprecedented rise of the Tennessee and Cumberland Rivers during 1927 was due to the heavy rains in western Tennessee and Kentucky during March and April. Numerous instances might be cited of severe floods in mountain streams due to continued rain for one or more days.

In general, the southeastern section of the valley through the mountains of Tennessee and North Carolina has its dry period during the months of March and April. This is probably because the storms are passing too far north to influence the extreme southeastern portion of the drainage basin.

Topography.—Mountainous lands and a small aggregate of valley lands occupy the eastern and southern part of the valley. Rough hill land extends along the front of the higher Appalachian Plateau from New York to Albama and reaches into eastern Ohio.

Other hilly regions are found in the Highland rim of Tennessee, the western coal field, the Knobs, and the Eden shale belt of Kentucky, in the Ozark section of Illinois, and the unglaciated section of Indiana. Steep bluffs are found along most of the main drainage channels. Very little of the Ohio Valley is so flat as to preclude erosion of soil when the land is cultivated.

Character of cover.—A fully stocked and well kept forest is the best type of cover for the prevention of erosion and of rapid run-off. When undisturbed by fire and grazing the hardwood forest develops a heavy leaf litter which, as it disintegrates, adds humus to the soil. It also provides a protection against the beating action of the rain, so that the soil remains in the loose condition in which it is left by the winter frosts. Thus in the deeper coves where heavy litter accumulates, soils are notably loose, sometimes to a depth of a foot. In the spruce type on the higher mountain tops a ground cover of sphagnum and other herbaceous vegetation builds up a peat-like structure which readily absorbs and retains moisture.

As the forest cover becomes thinner the leaf litter is exposed to more rapid disintegration, and the soil is exposed to packing by the rains and baking by the sun. Practically all of the forests in the Ohio Valley region except the relatively fire-resistant type on the mountain tops and in the deeper coves have been burned at some time; and through the southern portion of the Ohio Valley this burning has been repeated and severe. Cutting, burning, and the pasturage of stock have tended to open up the forest cover

and render it incapable of developing a heavy leaf mulch. For this reason the forest generally over the mountain section of the basin can not be given a 100 per cent rating as a protective cover. By continued fire protection and proper management of the existing stands, however, the density of the forest and the depth of the leaf mulch may be greatly increased.

Where farm woods lie adjacent to the fenced pastures, the common practice has been to include them in the pasture. The trampling of the cattle tends to pack the soil, while browsing opens the under 5 feet of woods within reach of the cattle, allowing wind to blow through and remove much of the leaf litter. Farm wood lots are typically open, often grass covered, and have little more value than pasture lands for the retention of water. With proper care and the prevention of overgrazing, pastures can probably be made perma-

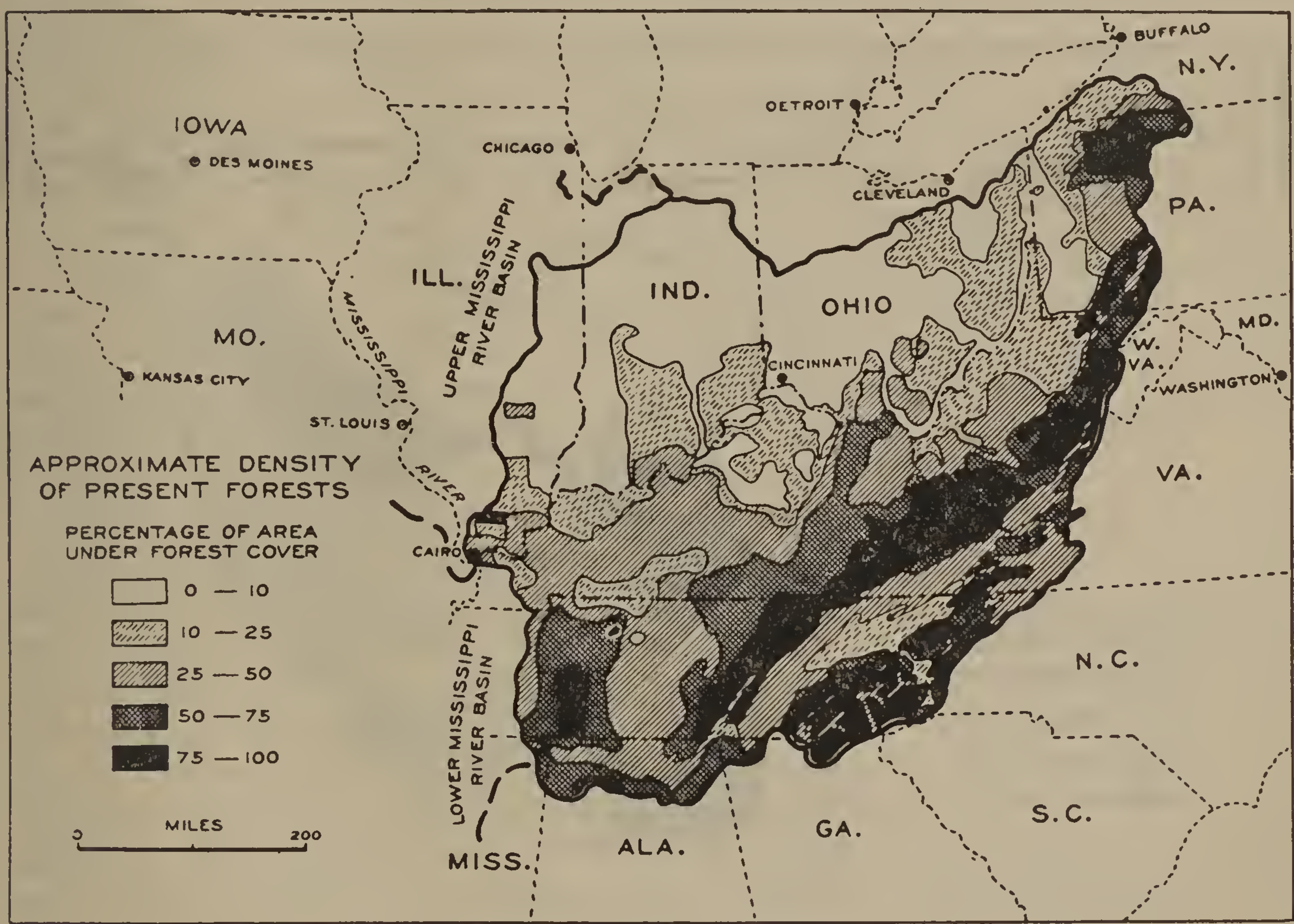

FIGURE 2.—Ohio River Basin

nent and a good sod maintained. On the steeper slopes pasture lands have a firm, packed soil, due to the tramping of the stock, and are not capable of quickly absorbing a heavy rainfall, even though the sod does prevent serious erosion. On steep hillsides where soils are coarse and sandy and lacking in lime a sod cover can be maintained only with difficulty, and erosion will ultimately take place.

Plowed lands are usually bare of cover in the fall and early spring at the time of the greatest rainfall in this basin. Such fields quickly establish water courses, and if the soils are easily eroded very soon develop gullies.

It becomes very obvious that the mountain and hill lands of the Ohio Valley must be retained either in forest or pasture-grass sod if erosion is to be prevented. If steep lands are cultivated, resort must be made to some practice of terracing or contour cultivation.

CRITICAL FOREST AREAS

APPALACHIAN MOUNTAINS

The Appalachian Mountain region is located in the drainages of the Hiwassee, Little Tennessee, French Broad, Holston, Kanawha, and Little Rivers. Steep topography, heavy rainfall, and erodible soils all make this a region of excessive run-off. A comparatively small portion of it is cultivated or is suitable for cultivation. Farm lands are being abandoned and many that are now in cultivation are washing severely. The need for protective covering in the higher mountains of this region has long been recognized. In order to prevent the silting of streams, which are considered navigable in their lower reaches, and additional reason for further protection by forests now exists in the increasing development of water storage, both

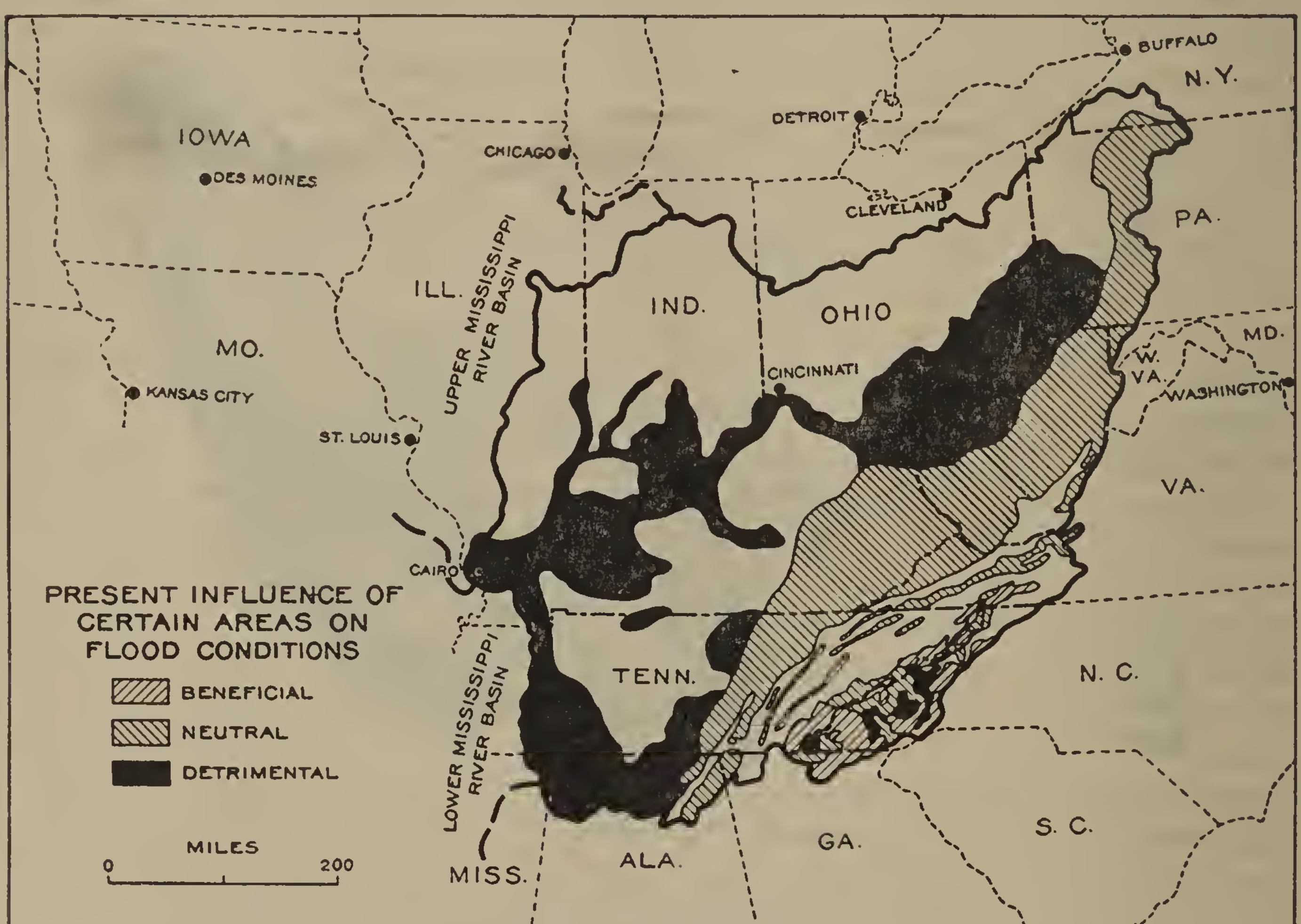

FIGURE 3.—Ohio River Basin

for city supplies and power purposes. The most careful treatment of land in this entire region is necessary if the rapid silting of reservoirs is to be prevented.

The reason for rapid erosion in this mountain district wherever land is exposed lies in its deeply weathered clayey soils heavily charged with mica, in the steepness of topography, the excessively heavy rains, and the fact that this section is not protected either by continuous freezing of ground during the winter or by snow cover. It is, therefore, subject to erosion practically throughout the winter, when there is the smallest amount of vegetative cover.

Recommendations.—Areas have already been set aside by the National Government within which purchases of forest land have been made. Large tracts have been organized into national forests. Such areas cover the higher and steeper mountain lands. The

recently designated areas included within the purchase unit for the Smoky Mountain National Park occupy the last extensive area of mountain land not previously designated as a purchase unit. In addition, however, there are many low lying ranges and hill farms now covered with forest because they are unsuited to other agricultural use. These lie outside the purchase units already designated, especially along the Blue Ridge southwestward from the junction with the Black Mountains, and along the Newfoundland and several other low ranges. It is recommended that this mountain land be put under organization as soon as possible to maintain an effective forest cover. This can be accomplished by (1) continuation of purchase of forest land within the purchase units already recognized by the Federal Government; (2) organization of land within the Smoky Mountain Park unit either for park or forest purposes; (3) purchase of land not otherwise organized, for State, county, or municipal forests (an instance of the latter already exists in the ownership of forest land by the city of Asheville for the protection of its municipal watershed); (4) a campaign of education supported by adequate development of timber marketing which will encourage private owners to protect and improve their woodlands.

The first step in the improvement of all this land is protection from fire; the second, the removal of cull material from the land to allow the young growth to increase the density of the existing stands. In case planting is undertaken, conifers should be given preference wherever they can be used, because of the better soil covering they afford.

Special mention should be made of the area on the Ocoee River about Ducktown, Tenn. In this section an area about 10 miles across has been entirely denuded by gases from copper smelting. In this instance erosion has already severely gullied the denuded area, and while some progress is being made in the reestablishment of vegetation by the removal of the cause of denudation, the reestablishment of a forest cover will be very slow because of the severity of erosion and the lack of seed trees. This is a specific instance in which planting is called for. The damage is made more serious by the existence of power dams on the streams below.

APPALACHIAN VALLEY

Within the Appalachian Valley is a series of high parallel ridges similar in structure to the plateau to the west of them. Some of them have sandstone caps but more often they are of shale and limestone structure. Because of their rugged topography and thin soils, they are unsuited to cultivation and are largely covered with timber. These ridges have been severely cut over, frequently burned, and generally heavily grazed. In no instance is the forest condition on these ridges as good as it can be made through fire protection and proper cutting practice. Outside of the regular county fire organization under the direction of State governments of Virginia and Tennesseee, no effort is being made to improve the condition of these ridges.

Adjoining the ridge lands are steep farm lands which have been cleared on shale and limestone soils. In some instances these have been abandoned and are seriously gullying.

Recommendations.—Forest cover should be restored on the ridges and badly gullied abandoned farm lands of the Appalachian Valley. In the case of the forest lands which have not been cultivated, this will occur naturally if protection from fire and grazing is given. Some of the farm lands will reseed naturally to stands of pine. Others on which gullying is already serious must be planted with trees. Forest planting is the best method of permanently correcting this gullied condition.

APPALACHIAN PLATEAU

The Appalachian Plateau includes all of the plateau region from Alabama to southwestern New York, starting as an abrupt escarpment or a series of folded ridges west of the Appalachian Valley and sloping westward to Ohio and the highland rim of Tennessee and Kentucky. This contains about 64,000 square miles, or nearly one-third of the area of the Ohio Basin. The western part of this plateau has a large proportion of agricultural land, but the eastern part is suited primarily for timber production.

This region includes a portion of the Allegheny, Monongahela, Little Kanawha, Kanawha, Cuyandot, Big Sandy, Licking, Kentucky, Cumberland, and the Tennessee watersheds. All but the Kanawha and Tennessee rise in the plateau. A rather abrupt escarpment marks its edge across Tennessee and Kentucky with a more gradual change in topography through the Allegheny portion. The plateau is already partially forested, but cutting and fire have reduced the effectiveness of the forest cover. Some of the cleared farm lands have been seriously eroded and subsequently abandoned. Most of these old fields are capable of reestablishing a forest cover.

Recommendations.—Within the plateau area, national forests have been established in northwestern Pennsylvania and northeastern West Virginia, and several areas of State forests have been set aside. The forest organizations thus far established by Federal and State Governments cover only a small part of the plateau region and are entirely inadequate to preserve the forest cover in good condition.

This great area has long been in need of the development of extensive publicly owned forests, both as demonstrations of the possibilities of benefit to be derived from proper forest management and as centers around which private owners can organize private property for protection from fire. Corporations holding large tracts of land for their mineral values can very well afford to utilize the surface for timber production. This should be encouraged by Government action to assist them in their organization work and relieve them from unfair tax burden.

KNOBS REGION OF KENTUCKY

An area of rough land located in parts of the Licking, Salt, Kentucky, and Green River watersheds, comprising about 2,218 square miles in area, is known as the Knobs region of Kentucky. In this belt, which is formed by irregular erosion of lower Mississippian rocks and the underlying shales, hills and ridges bearing thin soils have been left in a horseshoe formation bordering the blue-grass region. They now have a cover of scattered, poorly developed, and partially destroyed forests. Cutting, grazing, and fire have all assisted in creating this condition.

Recommendations.—These areas are too irregular in shape and too isolated to allow organization on a large scale. Some of them, however, are large enough to form into county or municipal forests. The State also may be able to establish in the region some small demonstration forests. The tendency in this region is rather to abandon farm lands than to clear more; and since the forest in its present condition is not adequate to conserve rainfall or to prevent erosion on recently burned areas, some steps should be taken to organize further demonstration areas. Planting may be required to reestablish the forests in many places.

WESTERN COAL FIELDS OF KENTUCKY

The western coal fields of Kentucky is an area of rough topography similar in geographic structure to the Appalachian Plateau except that it has not been elevated to such a height. A portion of it is covered with alluvial silt and it has a comparatively high percentage of river-bottom swamp land. This area, which has poor, sandy soil on the highlands and which is primarily valuable at this time for coal production, should be from 15 to 25 per cent in timber. The eastern end is best suited for forest areas.

HIGHLAND RIM

The highland rim in Tennessee is an elevated and much dissected plateau containing three to four million acres. The rougher portions are separated by the limestone lands of central Tennessee. The eastern section lies between the Cumberland Plateau on the east and the central basin. It extends from Overtown County south to Franklin County along the western edge of the plateau proper. The western section lies west of the central basin chiefly in Wayne, Lawrence, Perry, and Lewis Counties. Because of the rugged character of this land and its liability to erosion when cleared, it has been retained quite largely in forests.

Recommendations.—The areas of contiguous forests are not large enough in this region to justify the extensive organization of forest property, but suitable tracts can be secured to serve as small State or demonstration forests.

Areas should be selected for State-owned demonstration forests and county and municipal forests should be developed in so far as is feasible. The entire area should be brought under a central State fire organization which would protect both public and privately-owned forest lands. Where gullying has occurred, private owners should be encouraged to secure such land against further erosion by planting. The best means for doing this is extension work supported by a liberal system of tree distribution.

THE PLATEAU OF WESTERN TENNESSEE

West of the Tennessee River on a range of high land parallelling the course of the river lies an area very much subject to erosion. This condition results from a high precipitation, a soil of silt origin, and the fact that a large proportion of the area has been cleared

of its forest cover. Erosion on this hill land results in serious depletion of soil. Erosion can be checked best by planting in the heads of gullies where washing has rendered the land unfit for cultivation. This work is already being projected by the State Department of Forestry. Since the ownership of the land is largely in private hands, such work must be continued through the activity of the landowners aided by State cooperation.

OZARK REGION OF ILLINOIS

In the extreme south end of Illinois is an area of hill land which is really an extension of the Ozark uplift. This falls within the zone of the Illinois drift and the soil is very easily eroded. This area and a belt of bluff lands along the Mississippi River on the west side of the State are the logical sections for the development of the State-owned forests. The soil is badly eroded, the topography rough, and land prices are not so high as to prohibit purchases.

DRIFTLESS AREA OF INDIANA

The rough lands of Indiana lie largely at the southern end of the State. In the south-central portion is an area known as the driftless area, since it was not covered by the recent Wisconsin drift. It is an extension of the Knobs region of Kentucky. Rugged in topography and unsuited to agriculture, it constitutes the most heavily wooded section of Indiana and offers opportunity for the organization of State forests. Some land has already been acquired by the State on the edge of this region. Fire protection under State supervision should be given all wooded areas.

SOUTHERN OHIO

The three counties of Adam, Scioto, and Lawrence in southern Ohio contain the most heavily wooded section of the State. These counties all lie south of the Wisconsin drift area and are forested over about one-half of their surface. The land is roughly hilly with thin soils derived from shale and sandstone and in some instances from conglomerate. The valleys are narrow and cultivation has extended farther up the slopes of the hills than is justified. These highlands are being abandoned, and some of them have already been bought by the State and organized into a State forest. The forest has been cut over several times and is not entirely protected from fire.

The land in these counties requires adequate protection from fire, an extension of the State's forest ownership, planting of some of its abandoned land, and encouragement of forest development among the private landowners.

GENERAL SUMMARY

The forest lands of the Ohio River watershed play an important part in the whole Mississippi River problem. The higher mountain sections of West Virginia, Kentucky, Tennessee, and Pennsylvania particularly contribute to the high-water stages in the main river and if properly managed would be a marked influence upon the

run-off from these slopes, to say nothing of their very great influence upon erosion. In the lower sections of the Ohio River the forests upon the rougher, broken lands and upon waste lands not suited for agriculture, as along the streams, breaks, and rocky places, are essential and have a material effect upon the run-off from these localities. Although the forests may not seem to predominate, they are of considerable extent and of great importance from a flood-control standpoint. Proper forest management as a consequence is absolutely essential to make the forest lands of the most value from a protective standpoint.

As in all watersheds, it is necessary therefore that the steep slopes shall be kept continuously in forest. This is particularly true in many parts of this region because many soils are easily eroded and the run-off from denuded slopes is excessive.

In the general management of the forest in the Ohio River drainage, some system of selective cutting is necessary so that a cover can be maintained continuously. Cuttings should be so made that holes do not occur in the stand, that regeneration may be quickly brought about, and that large areas may not be cleared too rapidly.

Proper management can provide also for care in logging methods that the litter be not too greatly disturbed, and that conditions favorable for excessive run-off and for gullying may not be brought about. Logging by means of high-power machinery is in general unsatisfactory from a flood and erosion control standpoint.

Many parts of the region, such as the lands in Pennsylvania, Kentucky, Tennessee, and Virginia lend themselves to forest management. Lands are held in large blocks, are protected, and are operated for continuous wood production in many cases, and the forest is quite often held only as a supplement to the underlying coal deposits. Because coal is the primary resource it is possible to so handle the forest that a continuous crop of timber may be provided for the mining industry. Then too, many large areas are handled for the production of certain classes of products, which permit operation on a scale sufficient to provide for handling the land under good forest management.

Many of the areas of this section lend themselves to public forests, either as national forests, as State, or other local governmental forests. National forests have already been established on the headwaters of many of the streams draining into the Ohio, and an extension of these holdings is desirable. In the agricultural districts Federal ownership of land is not desirable, as the land is generally in small units not lending themselves well to efficient administration. Such lands could well be in the hands of the State, or, preferably, in the hands of counties or municipalities. In one or two instances cities have already begun the acquisition of forest land.

Forest planting is a necessary adjunct in good forest practice, and particularly so in this region. There are many eroded or denuded areas where planting will be necessary to provide a forest cover within a reasonable period. Forest planting may be brought about on an adequate scale through free distribution of nursery stock by States and through the increased participation of the Federal Government under the Clarke-McNary Act to this end. Planting is needed on many abandoned farm lands where the top soil has washed away and which have now been so reduced as to their productivity,

that they are no longer economically desirable for agriculture. Planting by the Federal Government is necessary on its lands, and on much of the land that will be acquired by States undoubtedly planting will be necessary.

Through the entire Ohio River Basin fire protection is absolutely essential. By reason of its removal of litter and its repeated damage to the forest soil, fire reduces greatly the water-holding capacity of the region, increases the flood heights, and paves the way for erosion. Much of the mountain lands are burned over annually by light ground or woods fires, and the area annually reported as burning over is undoubtedly small in comparison with the total area over which fires spread. The extension of the provisions of section 2 of the Clarke-McNary Act to the individual States and the increased participation in the way of funds by the National Government are necessary in order to bring about adequate fire protection. Although some areas are now given fairly good protection, many others are lacking in this regard, and throughout the entire region the protective work should be intensified.

One of the primary sources of erosion is the heavy pasturing of coniferous woodlands. Although it is not desirable from an economic standpoint to suggest that woods be not pastured, still there are many localities in which overgrazing has resulted in the loss of the valuable forage plants, has paved the way for erosion, and has prevented the establishment of a good forest and sod cover. In such areas proper pasture management would undoubtedly require a reduction in the number of stock so grazed or a reduction in the time in which the livestock are permitted on the lands. This form of damage is particularly important in the farm wood lots of the Central States.

Because of the character of the land, much land, particularly in the lower stretches of the river, is held by small owners. In order to reach these owners and teach them the proper methods of management for fire protection, and grazing management, an increase in the forest-extension activities of the States is necessary. This is in part provided for in the Clarke-McNary Act, and the extension work should be actively encouraged throughout the entire drainage area. Further extension work not provided by the Clarke-McNary Act is necessary in order to reach adequately the owners of large blocks of timberland. To this end congressional authority will be necessary.

Finally, research is necessary upon many phases of forestry work which have a bearing upon the flood-control problem. Some of these are provided for under the McSweeney-McNary Act, and additional authorizations are necessary for handling flood and erosion control investigations. Under this act it is possible to undertake studies of forest management and some such studies are under way; but these should be supplemented by investigations into such fields as the relationships of forests to run-off and erosion, and the development of the best methods by which erosion and flood flow may be controlled by forestry practices. On account of the very high percentage that the waters of the Ohio make in the Mississippi, normally about 40 per cent, it is necessary that such investigations be begun in the shortest possible time that the results of these studies may be available for application in any large-scale plan of flood and erosion control.

PART III

FOREST CONDITIONS WITHIN THE LOWER MISSISSIPPI RIVER BASIN

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CONTENTS

PART III

FOREST CONDITIONS WITHIN THE LOWER MISSISSIPPI RIVER BASIN

INTRODUCTION

Little is known of the occurrence of floods in the lower Mississippi River prior to 1798 except by tradition, but the notable floods of the nineteenth century were those which took place in the following years: 1815, 1828, 1844, 1849, 1850, 1851, 1858, 1859, 1862, 1865, 1867, 1874, 1882, 1884, 1890, 1893, and 1897. Those of the present century occurred in 1903, 1907, 1912, 1913, 1916, 1920, 1922, and 1927. The United States Weather Bureau in connection with measurements of river levels uses such terms as "flood stage" or "danger line." At points along the river "danger lines" have been set as representing heights of water at which the river is deemed sufficiently near to overflowing its banks to justify the Government in issuing warnings. Based on the occurrence of these dangerously high river stages, it has been shown [1] that the average interval between flood stages on the lower Mississippi River during the last half century was about one and one-third years, whereas similar records of the Red River covering a period of 38 years indicate an average interval of 3.8 years.

Severe floods occur every three to five years in the lower Mississippi River and very infrequently in the Red River. As indicated by charts showing highest and lowest annual river stages at various places during the last 40 years, the years when the high water exceeded the danger line or flood stage at Memphis and Vicksburg have been numerous, about two out of three. No great significance should be attached to differences between assumed danger lines and actual river stages as shown by the charts, because the former are changed by improvements in levees and the latter by crevasses.

The irregularity of stream flow is perhaps the most significant thing that these charts show. The highest water of the year has most often occurred during April or May. The most prolific rain-producing storms, of the "Southwest type," come with greatest frequency between January and April. Normal rains bring the lower Mississippi to a high stage by midwinter, so that the abnormally heavy rains coming about that time produce floods in the

[1] U. S. Weather Bureau. Monthly Weather Review. Supplement No. 22. The Spring Floods of 1922, by H. C. Frankenfield.

Mississippi before the normal Ohio flood stage is reached. Flood waters from the upper river may serve to prolong the high water in the lower Mississippi, but fortunately the annual floods in the lower river usually precede those in the upper river.

Adequate figures expressing the relation between discharge and precipitation have not been found in going over the literature on this subject. Considerable differences are found in the Weather Bureau's estimates of these ratios; for example, 22 per cent for the Red River and 52 per cent for the lower Mississippi. A quantitative study of precipitation and discharge data is needed to verify these figures.

Various studies of the movements of flood crests have been made but their behavior probably can never be expressed by a formula. It is generally estimated by the Weather Bureau that the flood crest in the lower Mississippi River proceeds at the rate of about 40 miles a day (river distance) between Cairo and New Orleans, but this rate is influenced by such factors as the relative position of any previous or subsequent minor crest. Rate of travel of flood crests depends largely upon hydraulic gradient, which in turn depends upon the rate at which a given volume of water is discharged into a stream.

According to Mr. Frank Carey, of the Mississippi River Commission, district No. 4, over 90 per cent of the sediment carried into the Mississippi comes from the western tributaries. Another statement attributed to one of the men in the office of the Fourth District of the Mississippi River Commission is that 90 per cent or more of the silt being carried at any one time by the Mississippi River represents material washed from its banks or from the levees. The number of reliable and comparable determinations of sediment upon which to base any comprehensive conclusions seems to be very inadequate. Considerable shifting of the channel of the main stream results from the moving about of quantities of material held temporarily in suspension.

Several instances of the cessation of navigation due to the silting up of smaller streams are related by Lowe.[2]

Discussing the tributaries of the Yazoo River, Doctor Lowe writes as follows:

> For years rapid and destructive filling has affected the Coldwater. Forty years ago boats of large size came up the river to Coldwater to load cotton. Now no kind of a boat can come up Coldwater River, so choked is it with sand bars. Thirty years ago a large fertile cotton plantation existed on the river flat just below Coldwater; for years past it has been abandoned, and is grown up in willow thickets, as useless land, all because the filling of the river channel has caused constant overflows on this land, covering it with sand beds.
>
> The Tallahatchie was formerly a navigable stream. Even as late as 1900 a small steamer drawing 4 feet of water plied on the Tallahatchie from Batesville downstream. Now the stream is choked with sand bars, and can be easily waded at almost any place. Coincident with this filling, I am told that the slightest freshet causes the stream to overflow and spread across its valley flat.
>
> An old and highly intelligent resident of Grenada remembers that before the Civil War large river boats came regularly up the Yalobusha River to Grenada to load cotton. This was the regular method of shipping the cotton crop of that day. No boat of any kind has run up the Yalobusha for many years. The stream is now so clogged with sand that even a medium-sized skiff would have difficulty getting up to Grenada, except in flood time.

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[2] Dr. E. N. Lowe, Reforestation, Soil Erosion, and Flood Control in the Yazoo Drainage Basin. Lumber World Review, Feb. 22, 1922.

Of the large creeks that flow out of this region into the Yazoo, the Big Sandy is fairly representative. This creek flows out of the hills of Carroll County; it is a stream notable for sand flats and dangerous quicksands. The writer made a special study of the filling from this stream in 1920. A large area adjoining the base of the uplands, as testified to by intelligent citizens, was 50 years ago a perfect swamp, with sloughs and even lakes upon which ducks in great numbers were killed every winter. At the time of my examination no wet lands, no sloughs, no vestige of lakes remained, but the whole area was in cultivated fields. Near the stream, at the base of the hills, the deposits are of sand: farther away the material becomes finer sand and silt, constituting, as just mentioned, a rich agricultural soil. A large drainage canal which passes through the area revealed at a depth of 10 feet beneath the surface, stumps of oaks from which the trees had been cut many years before. An old post which once supported a mail box shoulder high above the ground was so buried that one would have to stoop to touch the top of it. On every hand were evidences of rapid filling.

A tendency toward decrease in depth of the lower Mississippi River itself, if it exists at all, is not so apparent. It has been the opinion of many engineers that the building of levees would tend to deepen the main channel of the river. According to some 1,800 cross sections and 55,000 soundings made between the mouth of the Red River and the Gulf of Mexico in 1882, 1883, and 1895, and duplicated in 1921 and 1922, the depth of the Mississippi River has remained approximately unchanged. Similar results were obtained from a survey of the river north as far as Cairo. The figures in this case indicated a slight deepening of the river during the past 30 years, but this was not regarded as significant because the difference was well within the limits of probable error.

The following table gives the approximate area of alluvial bottom land subject to overflow in times past in that portion of the lower Mississippi drainage area included between the eighty-ninth and ninety-third meridians of longitude and south of the thirty-seventh parallel of latitude, by minor drainages. The extent of overflow during the 1927 high water is also given. These data have been obtained by planimeter from the map published by the Mississippi River Commission. (Map of the Alluvial Valley of the Mississippi River from the St. Francis Basin to the Gulf of Mexico, 3d edition. 1907. Scale 1 inch=5 miles, or 1:316,800:)

Drainage	Alluvial bottom land subject to overflow	Area overflowed in 1927
	Square miles	*Square miles*
Bayou Tallahala	15	15
Big Black	150	150
Homochitto	113	113
Yazoo bottom lands	6, 421	3, 450
Mississippi (direct)	10, 567	4, 459
Total, lower Mississippi	17, 266	8, 187

Alluvial bottom land and areas overflowed in 1927 in the lower Mississippi region (approximate figures)

Drainage or State areas	Map index No.	Alluvial bottom land subject to overflow	Area overflowed in flood of 1927
		Square miles	*Square miles*
Lower Mississippi (direct):			
Northern portion		7,801	2,835
Central portion		1,665	1,665
Southern portion		13,333	5,971
Total	40	22,799	10,471
Minor tributaries:			
Yazoo bottom lands	41	6,421	3,450
Homochitto	39	120	120
Bayou Tallahala	37	15	15
Big Black	38	150	150
Total		6,706	3,735
Major tributaries:			
Ouachita	72	7,201	6,781
Red	73	690	465
Arkansas	68	1,530	1,500
White	71	3,780	3,345
Total		13,201	12,091
Grand total		42,706	26,297
By States:			
Louisiana		20,033	12,556
Mississippi		7,276	4,065
Arkansas		11,257	8,641
Tennessee		750	
Missouri		3,210	1,035
Kentucky		180	
Grand total		42,706	26,297

NOTE.—These figures were computed by planimeter from data gathered by the Mississippi River Commission, after transferring areas from original map (scale 1/316,800 or 1 inch equals 5 miles) to base map (1 inch equals 40 miles). Planimeter work checked within less than 0.3 per cent, the errors necessitating adjustments of 40 to 60 square miles in the total areas in order to balance the table. No lands east of the eighty-ninth nor west of the ninety-third meridians of longitude nor north of the thirty-seventh parallel of latitude were included. See accompanying map.

GENERAL DESCRIPTION OF THE BASIN

Location and area.—The lower Mississippi River Basin, exclusive of the basins of the large tributaries entering it (Ohio, Missouri, Arkansas, and Red Rivers) and of certain indeterminate drainages noted below, covers a net area of 47,247 square miles. Portions of six States are included in this basin, which in the gross extends from southeastern Missouri to the Gulf of Mexico, a distance of over 600 miles, covering parts of southeastern Missouri, eastern Arkansas, Louisiana, and the western parts of Kentucky, Tennessee, and Mississippi. Its principal tributaries are the Little River in Missouri; the St. Francis River in Missouri and Arkansas; the Obion River in Kentucky and Tennessee; the Hatchie and Wolf Rivers in Tennessee and Mississippi; the Yazoo, Big Black, Bayou Tallahala, and Homochitto Rivers in Mississippi; and the Tensas River and its tributaries in Arkansas and Louisiana. The Atchafalaya River in Louisiana, together with an additional area of indeterminate drainage along the Gulf coast, has been excluded from the net area of the lower Mississippi River Basin for the purposes of this study. The area of the minor individual watersheds in the basin appears in an accompanying table (I).

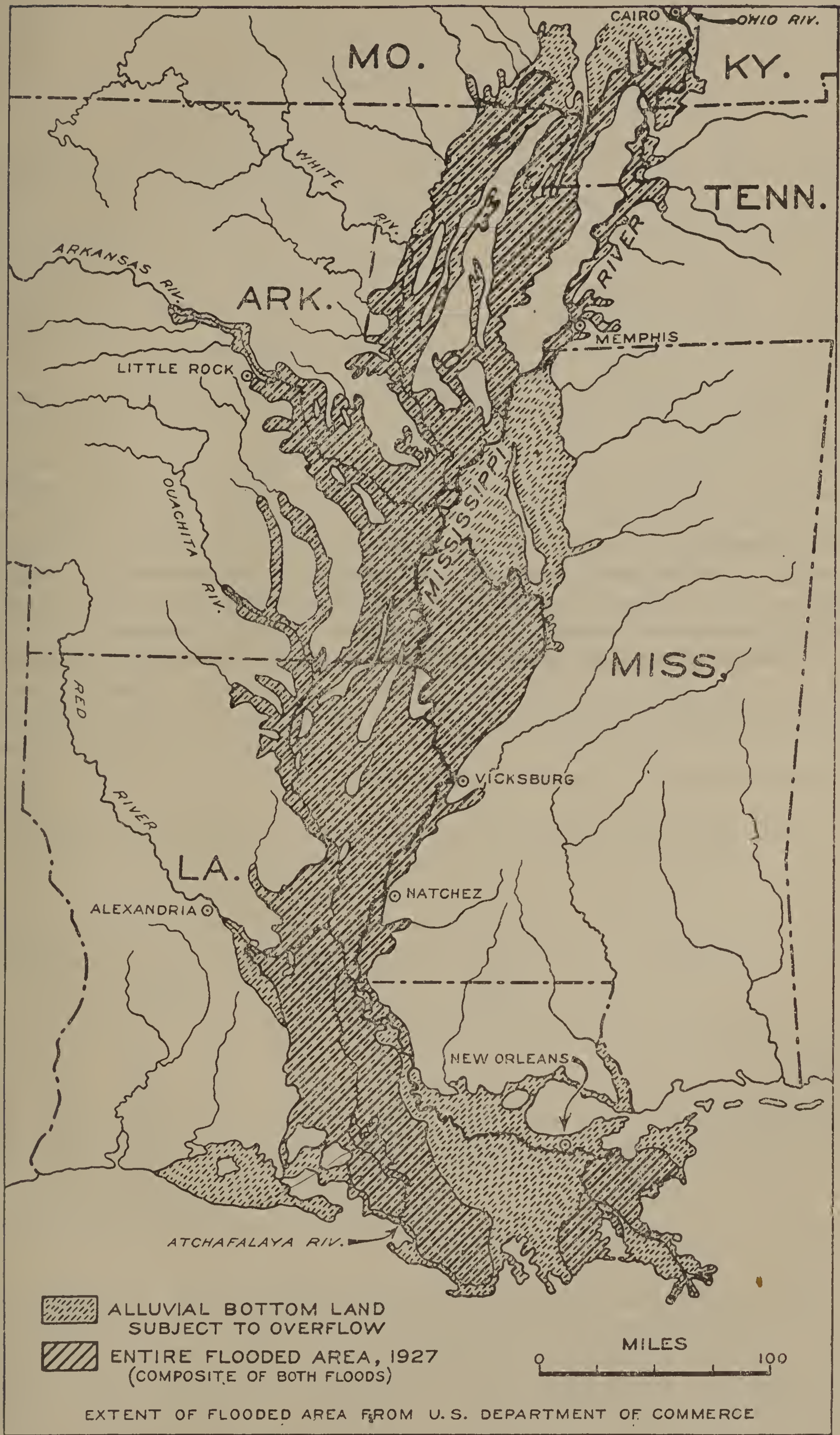

FIGURE 1.—Regions flooded in 1927

Topography.—The lower Mississippi River Basin varies in width from 50 to 150 miles; the broad, flat, flood plain of the Mississippi River extends throughout its length and ranges from 30 to 60 miles in width. The flood plain, which has been formed entirely by meander development and sidewise, bodily movement of the river as a whole, slopes very gradually southward from the region in southeastern Missouri, where the elevation is about 375 feet above sea level to the Gulf of Mexico. The river follows a very indirect course, which it is constantly shifting. This alluvial district is one of the most extensive of the really low areas of the continent, lying practically at base level. In the southern part of the district the surface approximates tide level and the outer border consists of permanent tidal marshes. The surface is very poorly drained, and bayous, lakes, and abandoned channels constitute an irregular maze of water upon a plain with scarcely perceptible slope.

On the east the Mississippi flood plain is bordered by a line of high bluffs, and on the west by a conspicuous ridge known as Crowleys Ridge, together with an alternating series of irregular bluffs and valleys south of this. The line of bluffs along the eastern edge ranges from 75 to 200 feet above the flood plain, and slopes off gradually to the eastward, where the topography becomes very rough and hilly only to shade off again to a more rolling country farther east. Elevations of the watershed range from sea level to over 1,000 feet in southeastern Missouri. The topography of about half of this entire lower Mississippi drainage basin can be classed as level; that of the remainder of the basin is about equally divided between rolling and hilly country. The area of each topographic type and the percentage which each forms of the individual drainage area is given in the following table:

Area and per cent of each topographic type in individual watersheds [1]

Tributary	Hills		Rolling		Flat		Total area (square miles)
	Area (square miles)	Per cent	Area (square miles)	Per cent	Area (square miles)	Per cent	
Bayou Tallahala	554	53	450	43	42	4	1,046
Big Black	2,491	70	570	16	498	14	3,559
Homochitto	302	24	782	62	176	14	1,261
Lower Mississippi (direct) determinate drainage	4,961	18	8,268	30	14,332	52	27,561
Yazoo (bottom lands)	586	8			6,738	92	7,324
Yazoo (highlands)	3,833	59	2,338	36	325	5	6,496
Total lower Mississippi	12,816	27	12,421	26	22,010	47	47,247

[1] Figures do not indicate the 5,441 square miles comprising the lower Mississippi (direct) indeterminate drainage.

Due largely to its rough and broken topography and to its fine silty soil, the Mississippi bluff region, which extends from the Mississippi River bottom lands to the rolling country east thereof is extremely susceptible to soil erosion. It is in this strip of country that the soil conservation problem for the watershed as a whole is most critical.

Geology and soils.—The Mississippi bottoms or "Delta" extending from Cape Girardeau, Mo., to the Gulf of Mexico, and including the

associated bottoms of the lower Arkansas and Red Rivers, comprises an area of approximately 45,862 square miles, or 29,351,680 acres.

The Mississippi bluffs and silt loam uplands border the Mississippi bottom lands on the east; these two regions are separated by a steep escarpment which rises 75 feet and in some places 200 feet above the bottoms.

Crowleys Ridge, composed of soil material similar to that found in the Mississippi bluff region, but located west of the Mississippi River, is a gently rolling country about 150 feet above the surrounding territory, and in places as much as 10 miles in width. It is probable that formerly these two regions were contiguous parts of the same soil formation.

The Mississippi bluff country is characterized by a silty material known as loess, which it is generally believed has been deposited there through wind action occurring over a long period of time. Winds have picked up these fine particles of silt from sand bars and beds which occurred along the Mississippi River and have deposited them to the eastward. These beds are deepest along their western border, often forming a mantle 40 or 50 feet deep near the bluffs, gradually becoming thinner toward the east, until in central Mississippi they finally give way to the sandy soils of the Coastal Plain.

The hilly country in southeastern Missouri which is included in this drainage is part of the northern Ozark soil province. A large proportion of the soils of this country is stony, the only productive land being located along strips of stream bottoms.

In the lower Mississippi drainage basin the predominating soil types along the river bottoms are clays and loams; in the Mississipi bluff region loams predominate.

River-wash deposits of the Mississippi River are so recent that no growth has developed upon them. The stream winds continually along its course. Its current is greatest on the outside of the curves where the banks take the form of concavities, and least on the inside of the curves, where the banks appear as convexities. As a result, the outside banks are cut away and the soil is deposited farther down the stream whenever the current slackens. Each flood forms new, and extends old, sand bars, with the result that the river's course shifts constantly; an area occupied by a sand bar or some other type of soil may in a few years be occupied by the main channel of the river.

The erosion of banks of the main channels as described above is very extensive; each year it results in the loss of much valuable agricultural land. In the southwestern part of the basin the soil of entire plantations has been washed away and deposited as worthless sand bars farther down the river.

Climate.—The mean annual precipitation varies from 45 inches near Cairo, Ill., to 56 inches near New Orleans, and averages about 52 inches, of which approximately half falls during the warm six months of the year. About 15 inches of rain usually occurs during March, April, and May. In 1927 about 21 inches fell during the shorter period of March and April. Such concentration of precipitation is a direct cause of floods. Abnormally heavy rainfall over longer periods does not ordinarily cause floods although it exerts an influence by increasing the high-water stages. According to

Frankenfield[3] floods may come from a single days' heavy rain over basins drained by swift and turbulent streams or from as much as two or three months' rainfall for the lower Mississippi River, which is more leisurely in its progress. Throughout the territory of the lower Mississippi the normal number of days per year on which 0.26 to 1 inch of rain falls varies from 30 to 40. Fortunately, rains of more torrential character occur less frequently toward the north. The average number of days in which more than 2 inches of precipitation occurs ranges from 2 to 3 near Cairo to 5 near New Orleans. Likewise, the number of days when torrents of more than 1 inch of rain per hour occur vary from about three at the northern extremity to six or more in southern Louisiana. Considering normal precipitation in the spring as well as totals for the year, the lower Mississippi has been given a rating of 60 in precipitation intensity.

The normal annual temperatures vary from 58° to 69° F., averaging about 65° for the year. January normals vary from 35° to 50°, averaging about 45°, and July normals are 80° or more throughout the territory. The average number of days with snow cover varies from less than 1 to about 10, but is only 3 for the area as a whole.

Historical development.—The first settlements were made along the Mississippi River early in the eighteenth century by the French. Spanish settlers appeared later on after this region had been ceded to Spain in 1762. However, there was no great wave of immigration until after 1803, when the United States came into possession of that portion of this drainage lying west of the Mississippi River. These early settlers came mainly from the Atlantic seaboard, some of them stopping off here on their way West, and, attracted by the fertility of the soil and becoming accustomed to the climate, made this their permanent abode. By 1840 there were settlements in nearly every part of this watershed.

The first settlers found this entire region, excepting the prairies in southern Arkansas and Louisiana and the tidal marshes near the coast, covered with a magnificent forest growth. Clearing for agriculture, supplemented by lumbering, has removed the greater part of this virgin forest. Development of the lumber industry has been of major importance only since 1900. The higher lands along the river and in the hill country were cleared first, mainly because such lands have better drainage and are less subject to annual spring inundation. The higher elevations in the bottoms adjoin the rivers and streams, and therefore they were among the first to be cleared. Even now in the bottom land country, cultivation is limited largely to these "frontage" lands. This initial clearing process involved wholesale destruction of the timber growth with no utilization except for local uses.

Cotton has been, and still is, the most important crop in both the uplands and lowlands; corn ranks second. Considerable sugar is being raised in the bottom lands of southern Louisiana. Rice, garden truck, and potatoes are grown on a smaller scale.

During and following the Civil War much of the plantation land was allowed to revert to forest, and even yet some of these old fields

[3] U. S. Weather Bureau. Monthly Weather Review. Supplement No. 22. The Spring Floods of 1922, by H. C. Frankenfield.

FIGURE 2.—Atchafalaya River, lower Mississippi River drainage. Melville, La. (Taken by Engineering Division, United States Army Air Service)

FIGURE 3.—Atchafalaya River, lower Mississippi River drainage, Melville, La. (Taken by Engineering Division, United States Army Air Service)

remain in timber. Many other fields, located mostly in the bluff region, have been wholly abandoned because the top soil has been allowed to wash away, thus rendering the land useless for further cultivation. In many places no adequate forest or other vegetative cover has become established on a great part of the abandoned land, and at the same time clear cutting, constant burning, and heavy grazing have reduced the protective vegetation on vast additional areas which have never been plowed. Hence there exists, in a locality of moderate to heavy rainfall, a series of catchment basins nicely calculated to discharge into the Mississippi, in the shortest possible time, the maximum amount of water burdened with the greatest possible amount of silt.

The severely eroded condition of this section of the Coastal Plain—the Mississippi bluffs and silt-loam uplands—has resulted in large measure from the removal of the forest cover and the abandonment of cultivated fields. Before the advent of the white man, natural drainage apparently did not cause unduly rapid dissection of the fertile, surface soil—a yellow loam from 3 to 7 feet in depth; but after the hardwood forest cover was removed during the settlement of the country and following the abandonment of many large plantations during the Civil War, a considerable part of this region, unprotected by forest cover or agricultural crops, was subjected to severe erosion. Year after year the fields were invaded by gullies of ever-increasing size and the fertile soil—of long geological growth—was carried away by the streams.

In the portion of this drainage lying to the west of the Mississippi River approximately 41 per cent, or 2,500 square miles, of the forested land is in farm ownership, together with approximately 57 per cent, or 2,500 square miles, of the unimproved land. The remainder of this forest and unimproved land, which includes many swampy and overflow areas, is largely in the hands of lumber companies. To the east of the river, however, about 55 per cent (6,500 square miles) of the wooded and forest land, and about 23 per cent (2,300 square miles) of the unimproved land, is farm-owned; unfortunately this will tend to make Government purchase of land for forest purposes difficult in this region in which it is most needed. No State or National forests exist in any part of this watershed.

As a whole, the region is still without stock laws, although Mississippi enacted such a law in 1927. Cattle range at large on any land not protected by fence; and such land includes practically all of the forested and cut-over land. Throughout the region it is customary to burn over annually, regardless of ownership, the woods and pasture land on which stock grazes; this custom arose from the belief that burning improves the range. Until recently these stockmen's fires, with other of various causes, were allowed to run absolutely unchecked, and they have lowered to a greater or less degree the protective value of lands not actually in cultivation. This is especially true of the upland portions to the east of the Mississippi River.

Conditions of nonforested land.—Practically all the land within the lower Mississippi Basin was originally in either bottom-land hardwoods, upland hardwoods, or pine. Within the boundaries of the bottom land hardwoods type lay all that part of the drainage west of the Mississippi, except for a relatively small area of upland

hardwood in eastern Missouri. To the east of the river was a narrow strip of bottom-land hardwoods with extensions running up the larger streams. North of the Big Black River in Mississippi the balance of the land was in upland hardwoods; south of the Big Black, pine predominated. To-day, as a result of clearing for agriculture and lumbering, only a little over a third of the total area of all types remains in woodland and forest. Because of differences in crops raised, methods employed, and results produced by cultivation the improved land will be discussed with reference to the forest type within the boundaries of which it falls. The percentile and absolute areas in cultivation, by forest associations within drainages, are given in an accompanying table (I).

Within the boundaries of the pine type, corn, cotton, and a little truck are the principal crops. All are open and intertilled, leaving the soil exposed to washing. Contour plowing, which affords some protection against soil wash, is fairly general throughout the type and almost universal on the steeper slopes and more erodible soils; terracing, which would be far more effective and is seriously needed in many places, is little used. Attempts have been made here and there to check erosion by means of brush. In general, even this precaution is evercised less than in the past, partly because of an increase in negro-tenant farming. Land is usually left without a cover crop during the heavy rains of winter. Plowing is shallow, and crop rotation is seldom practiced. In a country where cattle are left without shelter all or nearly all of the year, often on open range, little organic matter in the form of manure is available to add to the soil. Many eroded fields are abandoned and left to wash unchecked, while new fields, usually as steep and as unfitted for agriculture as the old, are cleared. As a whole, the cultivated lands in the pine type do more harm than good as far as flood control is concerned.

Conditions on the improved land within the upland-hardwoods type are as bad as, if not worse, than those just described for the pine. Similar crops are raised, but contour plowing and terracing are in general less effectively employed; and the soils, especially those of the Mississippi bluff lands, are even more subject to erosion.

Within the bottom-land hardwoods type the situation is vastly different. Drainage rather than contour plowing is generally needed and has been obtained on large areas in Louisiana, Mississippi, Arkansas, and Missouri. Cotton, corn, and sugar, with some truck and other minor produce, are the principal crops. Erosion is a minor factor on these lands and apparently tillage is beneficial rather than harmful in its effect on the absorptive power of the soil. Fields have continued to produce crops for over half a century instead of wearing out in half a decade as they often do on the upland slopes, and in some counties the amount of cultivated land actually increased between 1920 and 1925, a period during which the amount of cultivated land in the counties of the adjoining pine and upland hardwoods types decreased. This cultivated bottom land, however, lies where it can exert little or no influence in preventing floods, and is itself sometimes subject to inundation.

The unimproved land not in forest varies greatly in character not only between forest types but also between different parts of the same drainage within a given type. The relative and absolute

amounts within each type is given by drainages in an accompanying table (I).

In the pine type much land was dropped from cultivation between 1920 and 1925, and a considerable area has also been dropped before and since that period. Much of this land is eroding so badly that there is little or no chance for natural revegetation to take place. Other unimproved lands, especially in the southeastern quarter of the pine region in the portion of the drainage in Mississippi, are cut-over longleaf pine land, grazed as open range, burned over annually or nearly annually, not reproducing to pine, and supporting but a relatively scanty cover of bunch grass and scrub oak. Still other portions are reproducing in whole or in part to shortleaf and loblolly pine and to hardwoods, or support a good grass cover, but

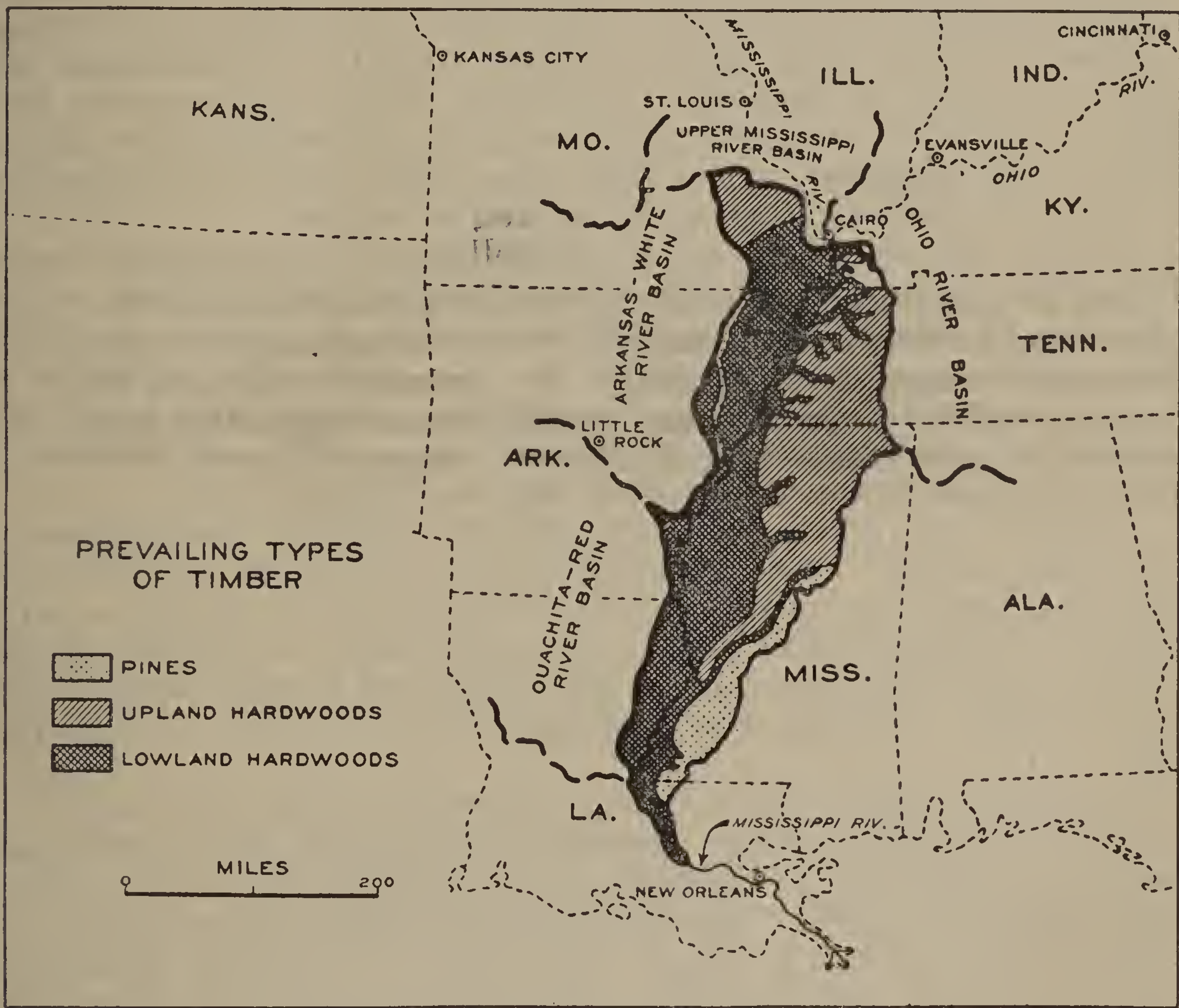

FIGURE 4.—Lower Mississippi River Basin

as a whole the unimproved lands in the pine type exert a decidedly detrimental influence in flood control.

The influence of the unimproved lands within the boundaries of the upland type is even more detrimental. In the upland hardwood type of the lower Mississippi as a whole a large aggregate acreage of formerly cultivated land was abandoned between 1920 and 1925; additional areas were abandoned before and after that period. As in the pine type, much of this abandoned land is eroding beyond any hope of natural revegetation. Some of the less badly eroded portions have been invaded by an effective cover of grass or of shortleaf or loblolly pine in the sections in which pine occurs; there are a few logged-off areas—never plowed—which are wholly or partially protected from

erosion by grass or oak brush. Annual or nearly annual fires are of common occurrence over the greater part of this type, especially in north central Mississippi and in parts of Tennessee, and there protection is most urgently needed. These fires check the development of an effective vegetative cover; they are especially fatal to young pines and destroy litter, undergrowth, and even some of the organic matter in the soil itself. In general they decrease the protective value of the unimproved land.

In contrast to the unimproved land described above is that found within the boundaries of the bottom land hardwoods type. Here relatively little cultivated land has been abandoned. A much larger proportion is composed of cut-over land, which has never been cultivated and which often is partially restocking to timber and almost always has a good brush or vegetative cover. A considerable though undetermined part is in swamps and lakes. Drainage projects seem to have had little effect on the storage capacity of these areas and grazing can not be considered injurious. Fires have occurred over most of the area every few years, reducing the effectiveness of the cover. This, however, is of small importance, since the location of the type is outside of all areas considered as critical.

Roadside ditches are among the miscellaneous areas included under the head of unimproved lands. Except within the boundaries of the bottom land hardwoods type, roadside ditches throughout the lower Mississippi drainage erode seriously. No systematic technique of erosion control for ditches has been worked out and applied on any considerable scale; hence these ditches are a source of tremendous loads of sediment for the streams into which they drain.

Condition of forests.—The distribution of forest associations or types has already been described in discussing the conditions of improved land. As in the case of forest cover the condition varies greatly in quantity and quality from drainage to drainage within a given type. A summary of the percentile and absolute areas in forest cover, for each type and drainage, is given in an accompanying table. (I.)

In the pine type there exists a variety of conditions which are determined partly by the character of the soil and topography, partly by the history of the region, and partly by the species of pine constituting the stand. The forests in the southeastern quarter of the pine type included in the major basin in southern Mississippi are nearly pure long-leaf pine. All of these long-leaf pine areas have been burned so heavily that underbrush and reproduction are at a minimum and litter is scant or lacking. Vegetative matter in the soil is very much reduced. Such forests exert relatively little protective effect. The balance of the forest in the pine type consists of short leaf and loblolly, occuring either in pure stands or mixed with various upland hardwoods, principally oaks, hickory, and some sweet gum. Toward the Big Black River this type becomes a transition type between pine and upland hardwoods. Fires occur frequently, but they are less common in the loblolly and short leaf than in the long-leaf region; the stands are denser, there is more brush and young growth, and litter and soil are generally in better condition. It should be noted, however, that litter never attains a great depth in the South even under fire protection, apparently be-

cause of the rapid breaking down of organic matter by fungi and bacteria. In the type under discussion, even when fires are kept out, litter very rarely exceeds a depth of 1 or 2 inches.

The upland hardwoods type, except for one area in the northernmost part of the basin in Missouri, is confined exclusively to the east of the Mississippi River. In extent, composition, and general condition it exhibits considerable variation from drainage to drainage. Upland oaks and several species of hickories are the principal species throughout; with them are associated many other hardwoods, including tulip poplar, sweet gum, and elm, and an increasing quantity of shortleaf and loblolly pine toward the southern boundary of the type. This boundary has been arbitrarily set at the Big Black River, but the forests immediately to the north of it are in reality part of a pine-hardwood transition zone similar to that described in connection with the pine type in Mississippi. Pure stands of pine and pure stands of upland hardwoods occur on both sides of the boundary. North of the Mississippi-Tennessee border and east of the Mississippi River very little pine is found; most of it is shortleaf. In that portion of the upland type in Missouri which is included in the lower Mississippi Basin shortleaf pine occurs in increasing amounts toward the west, becoming ultimately a pine type.

The upland hardwoods type is somewhat less severely burned than the pine type, though fires run through most of it every 3 to 10 years. In the Yazoo Highlands and in some counties in Tennessee large areas are burned annually or every other year. Grazing is general in the more open stands, but does not seem to be particularly destructive. The prolific sprouting of the hardwood species and the ability of shortleaf and loblolly to seed in rapidly on open areas keep the forest land in a moderately protective, if not in its most productive, state. Litter is scant or wanting, and at best is rarely more than an inch or two deep. The soil is much reduced in absorptive power by mismanagement of the forest with the result that the upland hardwoods forest, though in better condition than the pine as a whole, is still in need of great improvement as a protective cover with regard to floods. A much larger proportion of the woodland here is either in farm wood lots or broken up by cultivated land than in the pine or bottom-land hardwood types. This is an obstacle to Federal or State purchase for public forests, but is a decided advantage in fire protection and an aid in intensive forest management. Because of its common occurrence on steep and easily eroded areas the upland hardwoods type is particularly worthy of attention as a means of flood control.

The bottom-land hardwoods type, which also includes some cypress brakes, lies mostly to the west of the Mississippi, on areas of little importance with respect to run-off and erosion. Tupelo gum is the principal associate of the cypress, with many other hardwoods, including red gum, black gum, overcup oak, red oak, cow oak, water oak, elm, pecan, hackberry, willow oak, honey locust, maple, ash, cottonwood, haws, sycamore, hickory, persimmon, and box elder, coming in on the better drained lands. In this type less of the forest land is in farm ownership and more is in the hands of large lumber companies than in either of the other types. Fires are less common and occur very rarely in the wetter portions; grazing has practically no effect on the cover; and as a result there is denser stocking, more

brush, and heavier litter and humus here than in the uplands. A larger part of the land classed as forest has been cut over in this type than in the other two, but the cutting has been on more of a selection system so that the trees left, supplemented by sprouts and advance reproduction, almost completely cover the ground. Large areas are in overflow land and swamp. Some of these swamps have been drained, but no information is available concerning destruction of stands in the process. As protection forest the bottom-land hardwood stands are excellent, but no area even remotely critical is covered by this type.

Critical areas.—In the aggregate, there are but three distinct areas in the lower Mississippi River drainage which are critical from their character, present condition, and influence on floods. These, in the order of their relative importance from a flood-control standpoint, are: (1) A strip of country extending from western Kentucky to eastern Louisiana in the Mississippi bluff and silt loam upland soil region, covering parts of the watersheds of the Yazoo Highlands, Big Black River, Bayou Tallahala, Homochitto River, and some of the smaller tributaries of the Mississippi River, including the Obion, Hatchie, and Wolf Rivers; (2) the hill section of southeastern Missouri which is in the northern Ozark soil province and occurs within the watersheds of the Little and St. Francis Rivers in Missouri; and (3) Crowley's ridge, which extends from southeastern Missouri down into Arkansas and is located in part on the divide between the St. Francis and the White River Basins. Conditions on Crowleys ridge are somewhat similar to those found in Mississippi since the soils are identical in texture, and past agricultural practices have accounted largely for the erosion which has occurred in both places. Since Crowleys ridge does not represent an area sufficiently large to be of great importance, and as no recommendations covering it are being made, other than to stress the value of using simple soil conservation measures, no further comment seems necessary here.

Conditions in the Mississippi bluff and silt loam upland region are so serious that drastic measures will have to be taken to overcome the disastrous effects of the soil losses which have taken place, as well as to assure the proper management of these lands in the future.

Nowhere perhaps have the effects of gullying been as severe as in portions of northwestern and central Mississippi. This case is so instructive that it deserves a more detailed description. In the region in question, constituting a very desirable class of gently rolling uplands, which at one time was held to be the best cotton-growing portion of the State, the soil stratum consists of a yellow or brownish loam from 3 to 7 feet in original thickness. This region originally was covered by an open forest of hardwoods and an abundant growth of grasses that afforded excellent pasture to deer and cattle; it was a natural park, gay with flowers during most of the year.

When these lands were cultivated little or no attention was paid to the direction of the furrows; usually plowing was done "uphill and down," and the "dead furrow" resulted in the formation of washes which cut into the subsoil during the torrential rains that fell during the summers. Even when filled with soil by plowing, these washes would sometimes reopen during storms and shed the soil in a muddy flood upon the lands below. This erosion of the surface soil reduced the production of the higher lands and resulted in their neglect or

abandonment. The crusted surface shed the rain water into the old furrows, which quickly developed into deep, wide gullies or "red washes" and prevented any further cultivation. After a few years the soil stratum of brown loam was cut through to the loose, or loosely cemented, and easily eroded sand which underlies it almost everywhere. Then the water, increasing in volume as the gully enlarged, undercut the loam stratum and caused it to plunge into gullies in huge masses, which, with the sand, were carried into the valleys below, filling the beds of the streams sufficiently to obliterate

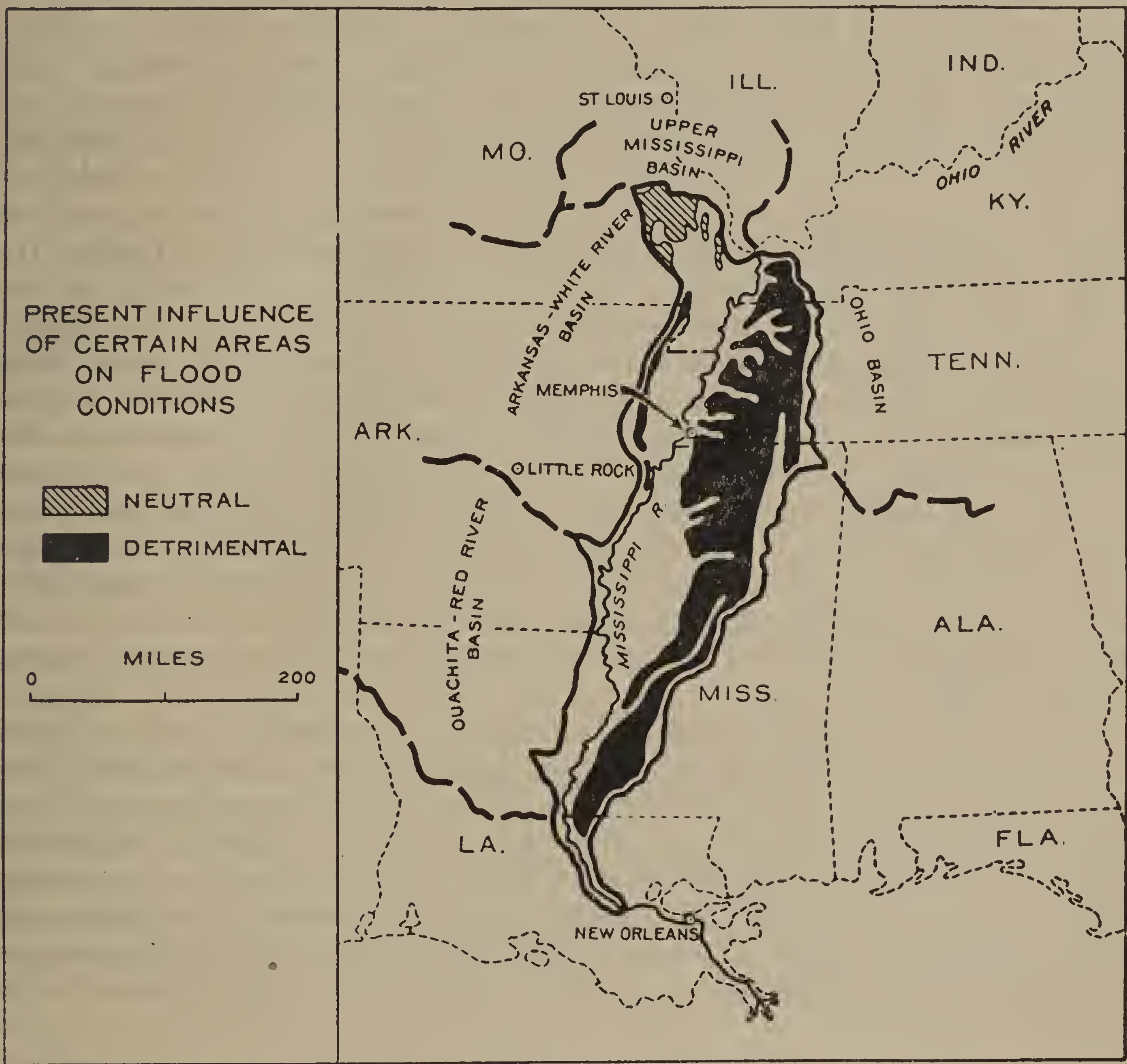

FIGURE 5.—Lower Mississippi River Basin

their channels. As erosion progressed large areas of uplands were denuded completely of their arable soil and nothing was left but bare, arid sand, wholly useless for cultivation. The valleys fared little better; the native vegetation was destroyed and the site was left to the conquest of hardy weeds.

In this manner whole sections, and in some portions of the State whole townships of the best class of uplands have been transformed into sandy wastes which are unreclaimable by ordinary means. Such erosion has wholly changed the industrial conditions of entire counties. In some instances county seats have had to be changed because the old town and site had literally "gone down hill" along with the rich agricultural soil. This destruction of lands was greatly aggravated by the Civil War, during which, and for some time after, large areas of lands once under cultivation were utterly neglected.

No adequate steps are now being taken in the Mississippi bluff country to reclaim eroded land formerly cultivated or otherwise deprived of its protective cover. Because of its topography and the peculiar nature of its soil, much of this land is totally unfit for agriculture and should be in productive private or public forest. The establishment of a new forest cover on an extensive scale is absolutely necessary to stop erosion. Fire protection offers the first means to this end. Where erosion is in the early stages and seed trees remain from a previous stand, the pine type may reestablish itself naturally where fire is kept out. In the hardwood type, however, and in the more seriously damaged lands in the pine type, many hundreds of square miles can be reclaimed only through forest planting. On the worst areas the technical problems involved are extremely complex, and reclamation research is urgently needed. It is highly probable that such engineering measures as the building of dams and terraces, together with the use of aggressive grasses, vines, and other herbaceous or woody perennials, must accompany the early stages of reforestation.

Once the steep-sided gullies and almost vertical bluffs are reduced to slopes which can support tree growth, and the soil is fixed by means of a forest cover, the protection which it gives must be vigorously maintained. Continued fire protection will be imperative. Selection cutting will necessarily replace the clear-cutting at present common throughout the region. In the Yazoo Highlands occasional small tracts of farm woodland can be found, on which fire has been kept out for a number of years, and leaf litter has accumulated to a depth of 2 or 3 inches. Such protected stands of timber amply demonstrate the effectiveness of a good forest cover in controlling erosion.

An estimate has been made of the relative protective value of each watershed on the basis of soil, physiography, precipitation, and general character of cover (including forest cover) as they influence erosion and rapid run-off. These ratings, on the scale of 100, indicate the relative importance in flood control and have been made for each cover type and different land use, both by minor drainages and for the major basin as a whole. The forest cover ratings appear in an accompanying table (II); a brief summary of all ratings for the watershed follows:

Drainage	Area (square miles)	Ratings					Forest cover rating			
		Soil	Physiography	Precipitation	Character of cover [1]	Average	Pine	Bottom land hardwoods	Upland hardwoods	All types
Bayou Tallahala	1,046	62	67	55	72	64	80	95	--------	80
Big Black	3,559	64	69	60	70	66	75	90	75	78
Homochitto	1,261	62	69	52	72	64	80	95	--------	82
Lower Mississippi (direct)	27,561	81	78	60	82	76	82	97	85	92
Yazoo (bottom land)	7,324	89	90	60	90	82	--------	95	80	94
Yazoo (highland)	6,496	62	69	60	67	65	--------	95	75	76
Total lower Mississippi	47,247	78	77	60	80	74	--------	--------	--------	89

[1] Character of cover includes not only forest cover, shown separately in this table, but also improved and unimproved lands.

Recommendations.—From the standpoint of flood control, the Mississippi bluffs and silt loam uplands in Kentucky, Tennessee, Mississippi, and Louisiana constitute the most critical area in the entire South. The topography is rough, the rainfall heavy, and the soil extremely susceptible to erosion. To make conditions worse, much of the forest has been logged off, and what is left has been subjected to repeated burning. Fires have also reduced the vegetative cover on unimproved land other than forest and have thus further increased run-off and erosion.

Injudicious agricultural practice, even on the land most suitable for cultivation, has resulted in appalling waste of soil resources, while futile attempts have been made to cultivate land which can be used profitably only for timber growing and hence never should have been cleared.

Man can not change the topography, climate, and soil, but he can modify his own use of the land. The fundamental mistake in this region, from the standpoint of soil conservation and flood control, has been an attempt to use true forest land for farms. To rectify this error and prevent further damage to the highlands themselves and to the drainages below, reforestation of the washed and gullied slopes is absolutely essential. The situation calls for drastic action, including not only immediate and thorough research to determine the best methods of planting or natural regeneration, but also the prompt application, over large areas, of the methods thus developed.

Reestablishment of a protective forest cover on the greater part of the critical area will not prove sufficient. Every possible precaution must be taken to maintain this cover for all time at maximum efficiency. The development of complete fire protection, while indispensable, is only a preliminary step; proper forest management, including the abandonment of clear-cutting for a system which will keep a perpetual cover on the soil, is also essential. Only in this way can the combined effects of rough topography, easily washed soil, and heavy rainfall be counteracted. Under an aggressive conservation policy such as this, destructive erosion in the uplands can be stopped, silting and sudden flood stages below will be reduced to a minimum, and, incidentally, maximum financial returns will be obtained from the region as a whole.

The fact that little or nothing has been or is being done toward establishing protection forests indicates that results can not be expected from the action of the individual landowners. Only through State or Federal action will adequate measures be assured. This no doubt could best be brought about by the establishment of State or national forests in those regions where the soil erosion problem is most serious. This refers particularly to north central and southwestern Mississippi and southeastern Louisiana. It is impossible to state at this time the approximate area of land which should be kept in forest cover for this district, but in many portions of Mississippi and in southeastern Louisiana it will run as high as 75 per cent. In this territory cultivation should be confined to land so level as to make control of erosion relatively easy.

In Tennessee and Kentucky a greater proportion of the land is in cultivation than farther south. Although conditions are not as critical as in Mississippi, it is believed that the highest use of the land

could be assured by the establishment of public forests; probably State-owned forests offer the best means.

State or Federal action to establish publicly owned forests will go far toward solving the question of erosion control in southeastern Missouri. That region, however, forms but a small part of a much larger area which extends into the adjoining watersheds to the west, where similar conditions prevail, and in making recommendations they should be considered together as a unit.

In the Crowley Ridge country and in other parts of the lower Mississippi drainage where topography is rolling in character, great care must be taken in the choice of agricultural methods employed if soil wash is to be held to a minimum. This will entail the general acceptance and practice of those methods which are known to be most effective in conserving soil; namely, contour plowing and terracing. Their attainment will be hastened by the educational measures already instituted by the county agricultural agents who, working in conjunction with extension foresters or State forestry departments, should not fail to stress the absolute necessity of fire protection as well as the value of leaving the rougher, steeper areas in forest and grass cover.

Throughout the critical areas erosion can be decreased by the use of winter cover crops, the incorporation of more organic matter into the soil, the rotation of crops, and by seeding up bare areas to sod grasses, Bermuda grass, white clover, lespedeza, honeysuckle, and other soil-binding vegetation.

RECAPITULATION

The needs of the lower Mississippi Valley fall into certain groupings which will be discussed under their appropriate headings.

Forest management.—Proper forest management is necessary on all forest lands. It is particularly important upon the critical areas in the various drainages described. This management demands such a system of cutting that some forest cover will always be retained to protect these lands from erosion. Some type of selective cutting is desirable, as clear cutting on the steep slopes leaves the land devoid of forest cover for too long a period. Logging on such lands should be so done as to prevent the formation of gullies which serve to accelerate erosion.

Forest planting.—Reforestation will be necessary on much of the abandoned farm land and on areas where erosion is already serious. Wherever the forest cover has been completly removed and there is little hope of obtaining a forest in a short time, it will be necessary to bring back the vegetative cover by artificial means. On pasture lands and worn-out areas, cooperation with the States under section 4 of the Clarke-McNary Act should be encouraged.

Protection from fire.—The habitual burning as practiced throughout the South must be stopped. Fire protection is of primary importance as the initial step in any system of forest regeneration. The present practices in the use of fire can be corrected only through the education of the local populace by extension activities. Further cooperation by the States under section 2 of the Clarke-McNary Act is desirable. With protection from fire, the forest litter will not only

prevent surface erosion, but will add humus to the soil, increasing its water-holding capacity, assisting materially in the reduction of floods and in the amount of material carried into the river.

Public ownership of lands.—In order to insure that lands are protected adequately from abuse, public acquisition by the Federal Government, States, or other political organizations is essential. In the Yazoo Highlands, the worst one-fourth or one-third of the area (1,600–2,200 square miles) is recommended for acquisition as a national forest. Public forests should be so located as to take care of this extremely serious situation. The present boundaries of the Ouachita National Forest should be extended to include other critical areas.

Agriculture.—As with forest lands, proper management of agricultural lands is of primary importance. Present practices resulting in erosion should be so modified by better methods as to increase water absorption, decrease erosion, and thereby assist in the solution of the Mississippi River problem.

Grazing practices, particularly in the Red River drainage, should be so modified as to permit the maintenance of a continuous and effective plant cover.

Forest research.—As so little is known as to the essential phases of the erosion and flood problem, research is badly needed. This involves studies of reforestation whereby planting can be made to stop erosion. Methods must be worked out and species must be determined that can be used to stop the erosion in the shortest possible space of time. As a supplement to planting, some forest-engineering technique should be devised, including such things as the possibility of contour plowing, or the use of check and wind dams and other similar terracing devices. Investigations are not needed to determine so much the quantity of erosion as the quickest possible methods of stopping that which is already in progress, and preventing further erosion from lands which are just now beginning to wash away. Of primary importance are the loess-soil area of the Yazoo, the hill sections in the State of Arkansas, and the "Breaks" of the Arkansas River in Texas. In the latter, some form of vegetation must be found which will be more effective and efficient than the present, and the proper methods of handling livestock must be worked out.

TABLE I.—*Area in each cover type by drainages*

Drainage, lower Mississippi River Basin	Pine association									Bottom-land hardwood association									
	Forest		Unimproved		Improved		Total		Per cent of total drainage area in association	Forest		Unimproved		Improved		Total		Per cent of total drainage area in association
	Square miles	Per cent	Square miles	Per cent	Square miles	Per cent	Square miles	Per cent		Square miles	Per cent	Square miles	Per cent	Square miles	Per cent	Square miles	Per cent	
37. Bayou Tallahala, Miss	340	33	464	45	227	22	1,031	100	98.6	8	50	4	29	3	21	15	100	1.4
38. Big Black, Miss	483	29	700	42	483	29	1,666	100	46.8	263	44	197	33	138	23	598	100	16.8
39. Homochitto, Miss	413	38	544	50	130	12	1,087	100	86.2	71	41	80	46	23	13	174	100	13.8
40. Lower Mississippi direct:																		
a. Little River, Mo										659	32	350	17	1,050	51	2,059	100	72.7
b. St. Francis, Mo.-Ark										2,519	42	1,500	25	1,980	33	5,999	100	85.0
c. Obion, Ky.-Tenn										153	27	153	27	260	46	566	100	12.0
d. Hatchie, Tenn.-Miss										74	29	74	29	108	42	256	100	9.4
e. Wolf, Tenn.-Miss										156	36	155	36	121	28	432	100	22.9
f. Tensas, Ark.-La										1,714	41	1,797	43	669	16	4,180	100	100.0
g. Atchafalaya, La.[1]																		
h. Miscellaneous:																		
Missouri										33	20	34	20	101	60	168	100	17.0
Kentucky-Tennessee										122	25	83	17	282	58	487	100	34.4
Mississippi	118	37	160	50	41	13	319	100	60.8	68	33	103	50	35	17	206	100	39.2
Do	153	36	233	55	38	9	424	100	80.2	35	33	70	67			105	100	19.8
Louisiana	77	29	111	42	77	29	265	100	36.7	82	18	334	73	41	9	457	100	63.3
40. Total	348	35	504	50	156	15	1,008	100	3.7	5,615	38	4,653	31	4,647	31	[2]14,915	100	54.1
41. Yazoo bottom lands, Mississippi										3,409	49	974	14	2,575	37	6,958	100	95.0
42. Yazoo uplands, Mississippi										169	44	84	22	130	34	383	100	5.9
Total lower Mississippi River Basin	1,584	33	2,212	46	996	21	4,792	100	10.1	9,535	41	5,992	26	7,516	33	23,043	100	48.8

[1] 5,441 square miles of indeterminate drainage omitted from this study.

[2] Excludes the Atchafalaya, with 5,441 square miles of indeterminate drainage. Including this, the total for lower Mississippi direct would be 33,002 square miles, and for the lower Mississippi River Basin, 52,688 square miles.

TABLE I.—*Area in each cover type by drainages*—Continued

Drainage, lower Mississippi River Basin	Upland hardwood association									Total of all associations								
	Forest		Unimproved		Improved		Total		Per cent of total drainage area in association	Forest		Unimproved		Improved		Total		Per cent of total drainage area in all associations
	Square miles	Per cent	Square miles	Per cent	Square miles	Per cent	Square miles	Per cent		Square miles	Per cent	Square miles	Per cent	Square miles	Per cent	Square miles	Per cent	
37. Bayou Tallahala, Miss.									0	348	33	468	45	230	22	1,046	100	100
38. Big Black, Miss.	505	39	466	36	324	25	1,295	100	36.4	1,251	35	1,363	38	945	27	3,559	100	100
39. Homochitto, Miss.										484	38	624	50	153	12	1,261	100	100
40. Lower Mississippi direct:																		
a. Little River, Mo.	325	42	194	25	256	33	775	100	27.3	984	35	544	19	1,306	46	2,834	100	100
b. St. Francis, Mo.-Ark.	445	42	434	41	180	17	1,059	100	15.0	2,964	42	1,934	27	2,160	31	7,058	100	100
c. Obion, Ky.-Tenn.	1,240	30	1,240	30	1,654	40	4,134	100	88.0	1,393	30	1,393	29	1,914	41	4,700	100	100
d. Hatchie, Tenn.-Miss.	987	40	765	31	715	29	2,467	100	90.6	1,061	39	839	31	823	30	2,723	100	100
e. Wolf, Tenn.-Miss.	408	28	480	33	568	39	1,456	100	77.1	564	30	635	34	689	36	1,888	100	100
f. Tensas, Ark.-La.										1,714	41	1,797	43	669	16	4,180	100	100
g. Atchafalaya, La.[1]																		
h. Miscellaneous:																		
Missouri	328	40	98	12	394	48	820	100	83.0	361	37	132	13	495	50	988	100	100
Kentucky-Tennessee	167	18	213	23	547	59	927	100	65.6	289	20	296	21	829	59	1,414	100	100
Mississippi										186	35	263	50	76	15	525	100	100
Do										188	36	303	57	38	7	529	100	100
Louisiana										159	22	445	62	118	16	722	100	100
40. Total	3,900	34	3,424	29	4,314	37	11,638	100	42.2	9,863	36	8,581	31	9,117	33	[2]27,561	100	100
41. Yazoo bottom lands, Mississippi	139	38	125	34	102	28	366	100	5.0	3,548	48	1,099	15	2,677	37	7,324	100	100
42. Yazoo uplands, Mississippi	2,262	37	2,139	35	1,712	28	6,113	100	94.1	2,431	38	2,223	34	1,842	28	6,496	100	100
Total lower Mississippi River Basin	6,806	35	6,154	32	6,452	33	19,412	100	41.1	17,925	38	14,358	30	14,964	32	[2]47,247	100	100

[1] 5,441 square miles of indeterminate drainage omitted from this study.
[2] Excludes the Atchafalaya, with 5,441 square miles of indeterminate drainage. Including this, the total for lower Mississippi direct would be 33,002 square miles, and for the lower Mississippi River Basin, 52,688 square miles.

TABLE II.—*Cover ratings, lower Mississippi Basin*

Drainage area and State	Pine				Botton-land hardwoods				Upland hardwoods				Total all types			
	Forest	Unimproved	Improved	Total cover	Forest	Unimproved	Improved	Total cover	Forest	Unimproved	Improved	Total cover	Forest	Unimproved	Improved	Total cover
37. Bayou Tallahala, Miss	80	60	85	72	95	80	90	90					80	60	85	72
38. Big Black River, Miss	75	55	70	65	90	75	90	85	75	60	70	68	78	60	73	70
39. Homochitto River, Miss	80	60	80	70	95	80	90	88					82	63	82	72
40. Lower Mississippi direct:																
a. Little River, Mo					95	75	90	89	85	65	70	75				
b. St Francis River, Mo.-Ark					95	75	90	88	85	65	65	73				
c. Obion River, Ky.-Tenn					100	80	90	90	85	60	70	71				
d. Hatchie River, Tenn.-Miss					100	80	90	90	85	60	70	73				
e. Wolf River, Tenn.-Miss					100	80	90	90	85	60	70	71				
f. Tensas, Ark.-La					100	85	95	93								
g. Atchafalaya River, La.[1] (summary	80	55	70	59	100	85	95	89								
of cover ratings)					100	90	95	91								
h. Miscellaneous direct:																
Missouri					95	75	90	88	85	65	70	75				
Kentucky-Tennessee					100	80	90	91	85	60	70	70				
Mississippi	80	70	80	75	95	80	90	87								
Do	80	70	80	75	95	80	90	85								
Louisiana	90	65	70	74	100	90	90	92								
40. Total	82	69	75	74	97	81	91	90	85	61	70	72	92	72	81	82
41. Yazoo bottom lands, Mississippi					95	80	90	91	80	60	65	69	94	78	89	90
42. Yazoo uplands, Mississippi					95	80	85	88	75	55	65	65	76	56	66	67
Total lower Mississippi River Basin													89	68	80	80

[1] Consists of 5,441 square miles of indeterminate drainage, excluded from this study

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Mississippi.—Adams, Alcorn, Amite, Coahoma, Copiah, Chickasaw, Choctaw. Grenada, Hinds, Holmes, Issaquena, Lafayette, Lincoln, Madison, Montgomery, Prentiss, Rankin, Simpson, Sharkey, Warren, Wilkinson, Yazoo.

Missouri.—Cape Girardeau, Dunklin, Perry, Saint Francois.

Oklahoma.—Bryan, Canadian, Johnson, Marshall, Roger Mills.

Tennessee.—Henderson, Henry, Madison, Shelby.

Texas.—Armstrong, Bowie, Briscoe, Camp, Carson, Castro, Childress, Collingsworth, Cottle, Deaf Smith, Delta, Dickens, Donley, Farmer, Floyd, Franklin, Gray, Grayson, Hale, Hall, Harrison, Hemphill, Lamar, Morris, Motley, Potter, Randall. Red River, Titus, Swisher, Wheeler.

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PART IV

WATERSHED CONDITIONS WITHIN THE MISSOURI RIVER BASIN

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CONTENTS

PART IV

WATERSHED CONDITIONS WITHIN THE MISSOURI RIVER BASIN

INTRODUCTION[1]

LOCATION AND AREA

This great drainage basin comprises 43 per cent of the Mississippi watershed. The extent east and west is about 1,200 miles; north and south it is about 900 miles. The area is a roughly elongated oval with its long axis, northwest and southeast, about 1,400 miles and the short axis about 600 miles.

The major watercourse generally holds to the northeastern side of the oval. The tributaries are mostly in the upper part of the basin and from its western side. The most important are the Cheyenne, Kansas, Little Missouri, Milk, Musselshell, Niobrara, Osage, Platte, Yellowstone, and White Rivers.

Included in the drainage are all or parts of 10 States. These, with the area of each in the drainage, are as follows:

State	Square miles	State	Square miles
Colorado	29, 551	Nebraska	77, 520
Iowa	17, 366	North Dakota	38, 846
Kansas	40, 471	South Dakota	75, 222
Minnesota	1, 983	Wyoming	73, 063
Missouri	36, 440		
Montana	121, 174	Total	511, 636

In addition an area of about 12,934 square miles lies in the Dominion of Canada, in a strip just north of the State of Montana. The total area in round numbers is, therefore, 525,000 square miles.

[1] On account of the great size of the Missouri watershed the basic work was divided among three agencies. The reports for tributaries from the head of the Missouri to but not including the Cheyenne River were prepared by representatives of the northern Rocky Mountain district of the Forest Service (Missoula, Mont.). Representatives of the Rocky Mountain district (Denver, Colo.) reported on the tributaries, beginning with the Cheyenne, as far as the State of Missouri. Below that point the basic work was done by W. W. Ashe, of the Eastern National Forest District (Washington, D. C.). This regional report for the Missouri Basin as a unit was written by Mr. M. H. Wolff, compiling the tributary reports with other material. Because of pressure for time, it was not possible to precede all the reports, prepared in the summer of 1927, with a complete study of every possible source of information. Hence some of the data or descriptions may be found incomplete. Sufficient indices were obtained, however, to support the conclusions drawn.

LAND OWNERSHIP AND TYPE DISTRIBUTION[2]

In the timber belt about two-thirds of the total area of about 35,000 square miles is forested, the remainder being range, cultivated land, or the very negligible barren.

Ownership is, roughly:

National forest (net area within boundaries), 72 per cent; about 85 per cent timbered.

National Parks, Indian and other reservations (net area within boundaries), 6 per cent; parks mostly timbered; others mostly range.

Public domain, 10 per cent; practically all range.

State, 1 per cent; chiefly range lands.

Private (including private owned in national forests and parks and other reservations), 11 per cent; about 90 per cent range or farm.

The high mountain pine forests are largely Federal property. They lie mostly in the national forests, with portions in the national parks and Indian reservations, and small aggregate is public domain. Inside the national forests about 2,900 square miles, or about 10 per cent of the total national forest area, is privately owned.

Of the grazing belt about 11.5 per cent is public domain; a negligible aggregate lies in Federal or State reservations, and the great proportion is privately owned. The public domain is practically all range land or Bad Lands; it is estimated that only a negligible portion has any farming value or forest value. The reserved lands are primarily range lands, though an appreciable percentage (figure not available) can be classed as timbered of light forest character. The private land is primarily range, less than 30,000 square miles, or about 13 per cent, being under cultivation.

In the agricultural belt practically the entire ownership is private.

The national forests confined almost wholly to the timber belt aggregate approximately 28,000 square miles gross area (or about 5.3 per cent of area of the drainage) and about 25,000 square miles net.

The public domain lands in the Missouri River Basin are distributed about as follows:

	Square miles
Montana (29 per cent)	8,900
North and South Dakota (2 per cent)	650
Wyoming (67 per cent)	20,850
Colorado (2 per cent)	550
Nebraska	50
Total	31,000

Roughly:

	Square miles
In the timbered belt (11 per cent)	3,400
In the grazing belt (89 per cent)	27,550
In the agricultural belt	50
Total	31,000

All but a very small percentage can be classed as nontimbered nonagricultural land (including Bad Lands and other waste). About

[2] In all places in this report where rough aggregate figures are given, they are to be taken as indicative but in nowise exact. Also, water surface being less than three-fourths of 1 per cent of the area has been disregarded, the indicative value of the figures not being affected.

140 square miles which have heretofore been recommended for addition to the national forests under the Clarke-McNary Act are primarily forested. This is less than one-half of 1 per cent. Such additional recommendations as are yet to be made will not change the aggregate from well under 1 per cent of the total.

Roughly, the distribution of land in the Missouri drainage is:

	Square miles
Forested (about 6 per cent)	31, 500
Improved (cultivated and pastures) (about 26.7 per cent)	140, 000
Unimproved (range and pastures, waste, etc.) (about 67.3 per cent)	353, 500
Total	525, 000

TOPOGRAPHY

Topographically the basin is most varied. About one-twelfth of the surface is mountainous, about one-sixth plains, and the remaining three-fourths is rolling. About 75 per cent of the drainage lies at elevations between 1,000 and 5,000 feet above sea level, with about 7 per cent between 100 and 1,000 feet, and about 19 per cent over 5,000 feet, including mountain ranges and peaks well above 10,000 feet.

The mountain area consists principally of a strip varying in width from just a few to about 100 miles along the western edge of the basin; in addition a number of relatively small mountain area outposts lie within the rolling country. The mountains along the Continental Divide are very broken, rugged, and steep. Crests and peaks and in some localities high rolling plateaus going up 9,000 to 11,000 feet or more rise above generally V-shaped valleys, whose elevations run about 5,000 to 6,000 feet.

Within a few miles of some of the higher mountain crests are the upper limits of the rolling lands in the valleys at an elevation of about 4,000 to 5,000 feet. Progressively away from their beginnings, the valleys broaden out to merge with the rolling and plains region.

The general rolling country presents broadly a wide area of tabular surfaces, traversed by broad shallow valleys or large rivers rising mainly in the Rocky Mountains, and more or less deeply cut by the narrow valleys of lateral streams. Smooth surfaces and easterly sloping plains are characteristic features, but in portions there are low hills and buttes, extended escarpments, and scattered areas, mainly paralleling the watercourses, but elsewhere in rather large blocks, of Bad Lands. Wide regions of sand hills surmount the plains in some localities, notably in Nebraska.

The watercourses vary from swift mountain torrents to wide, slow-flowing rivers. In the mountains normal velocity is 2 to 4 miles per hour with no outstanding increase in times of high water. The major portions of the streams in the upper half of the drainage run through the plains section at about 1½ to 2 miles per hour in normal stages and up to 4 or 5 miles per hour during flood periods. In the lower portions of the basin the main watercourses and tributaries flow much more slowly both at normal stages and when in flood.

Formed at an elevation of 4,300 feet by the junction of three mountain rivers, 2,800 miles from its mouth, the Missouri River for the first 150 miles is generally a rapid mountain stream flowing northerly through mountain valleys alternating with deep canyons which occa-

sionally open up to rolling country. The bed is generally rocky and shifts but little. From near the town of Great Falls, Mont., the gradient becomes much less, averaging 2.5 feet per mile to the mouth of the Yellowstone, 750 miles lower down. In this generally easterly flowing stretch, the river gradually begins to take on its distinguishing characteristics. It becomes wider, more turgid, more shifting of channel, and more sinuous.

From its junction with the Yellowstone the Missouri definitely assumes the character which it maintains to its mouth. Broadly characterized, it is a greatly meandering wide watercourse with a gradient of 1 foot per mile, in a flood plain one-half to 5 miles wide flanked by "breaks" rising 200 or more feet to the level of the surrounding terraces and rolling country. The bed is mostly sand and silt, generally moving either to one side or the other as the banks are worn away, with a low-water channel which is much narrower than the high-water width, and often changed after the subsidence of the high waters through the shifting of sand bars. The banks are mostly low and readily overflowed in high water.

For the most part the upper tributaries are somewhat similar to the upper portion of the main stream—swift flowing, and for the relatively small portion of their length in the mountains, with rapids, falls, and gorges, and with bowlder-strewn, gravelly, and distinct channels; and after reaching the plains country changing gradually to slow, sluggish, meandering streams with sand bars or islands and generally low banks, with their flood plains generally entrenched within the "breaks" from the surrounding country.

From eastern Montana to the Mississippi the tributaries have broad flat beds, heavily sanded, and in low water are rather shallow with very light flow. Some of the tributaries, noticeably the James and the Powder Rivers, become in low water little more than a series of pools. The bluffs or "breaks" of the tributaries often become higher as the major watercourse is approached.

Generally the lower portions of the upper tributaries and the lower tributaries are much subject to bank caving, change of low-water channel, and the movement of stream beds, from side to side. The effect of high water is often to move eroded bank material from one place to another lower down in the stream, again later to be picked up and moved on farther, until ultimately deposited in the lower Mississippi or its Delta. This deposit and redeposit of silt is a distinct characteristic in the flashy tributaries like the Powder and Little Missouri. During local storms on these and their minor tributaries large quantities of soil are brought from the higher levels to the main watercourse and there deposited. During times of spring flood in the main watercourse, these deposits are again taken up and deposited lower down or become part of the silt carriage to the lower Mississippi.

Limited swampy areas lie along some of the tributaries in the mountains. While in the aggregate such swamps cover a large area, their proportion to the whole drainage is so small that they have negligible effect on run-off, except in very localized districts. Relatively small areas of swamp along the lower reaches of the Missouri are also not more than of local importance.

FIGURE 1.—Confluence of Missouri and Yellowstone Rivers, Mont. Broad slow moving rivers in ordinary stages. Banks much subject to caving and low-water channel to frequent changes. River beds are silt and mud

In the mountains practically every minor tributary has small lakes at its headwaters. Only a few of the streams have appreciable natural storage capacity in the form of larger lakes. At the higher altitudes, above timber line generally, are permanent snow and ice fields and small glaciers which feed out their waters gradually during the warm summer periods.

Two outstanding subterranean reservoirs are noteworthy. The sand-hill country of Nebraska absorbs the rainfall almost completely and then releases it through springs. The heavily glaciated "pot-hole" country to the east of the Missouri River, including the James River watershed in the Dakotas, also absorbs considerable of the precipitation, with the result that there are no large surface flows from here.

On a great many of the streams, particularly in the mountain regions, irrigation and power reservoirs have been constructed. Their effect on local streams is felt at times of high water, but there is only one important tributary, the Platte River, where such effect is material in mitigating high water at flood periods.

GEOLOGY AND SOILS

From the mountain rim of principally igneous and metamorphosed rocks—granites, gneisses, and schists, and from similar formations of the outpost mountain groups—stretch the plains areas consisting of a great thickness of soft rocks of sedimentary origin. These deposits lie on relatively smooth surfaces of the older rocks. "The materials of these formations are derived mainly from the west and were deposited layer by layer during earlier times in the sea and late by streams on their flood plains or in lakes. Aside from a few local flexures the region has not been subjected to folding, but has been broadly uplifted and depressed successively. The general smoothness of the region to-day was surpassed by the apparently almost complete planations of the surface in earlier epochs."

In addition to small localized areas, chiefly among the mountains, one or more successive ice sheets covered a narrow east and west strip in Montana north of the Missouri River, and practically all of the country along the Missouri and northeast of it to the limits of the drainage, in the Dakotas, Iowa, and Missouri. These have left extended areas of glacial drifts of varying depth which has in varying degrees been removed by erosion.

Loess and sand deposits of a later geological period also are found in many localities, the former particularly in the southeastern portion of the basin and the latter principally in Nebraska.

As a whole, the surface formations, except in the mountains, break down readily and form freely erodible soils.

Soils are principally loams varying from sandy, gravelly phases in the mountains to heavy clay loams everywhere in the rolling country, especially in the northern half. Next in importance are the clays, occurring pretty generally in eastern Montana and western Dakotas. Sands prevail in Nebraska. Of gravels there is only a very limited quantity. The loess beds occupying a large area in the lower portion of the basin produce a silty loam. In the mountain areas disin-

tegration of rock in place has formed gravels which graduate lower down in elevation into gravelly stony loams, and in the valleys below them to silty loams.

The clays and heavy clay loams in the semiarid section and the loessal silt and silt loams in the humid regions erode very readily. They are unstable even in districts of subdued topography. Extreme cases of clay soil erosion are represented in the Bad Lands. Depending on slope and age of erosion the types of erosion are progressively sheet, shoestring, and gully. The sugarlike erodible loess soils are noteworthy in the region of the lower Missouri, especially along the river bluffs.

The gravels and gravelly loams in the mountain belts are not so readily erodible, even though often on steep slopes. Only the normal, usually sheet, erosion occurs.

The sands are very stable.

The glacial till areas vary from clay loams to sandy silty loams; on the whole they are not badly erodible. Their depth is usually great enough that the subsoil from the geological formations has only a minor influence. However, stream cutting has frequently exposed the more erodible soils beneath these deposits. Hence, there very frequently exists a condition of steep slopes and heavily erodible soils along the river "breaks."

The major proportion of erosion and silt carriage of streams comes from the clays in the northern part, the Dakotas, Montana, and Wyoming, subject as they are to alternating dry, hot periods and torrential showers, and from the loess-formed silty loams in the southern intensively cultivated portion.

The clays and heavy clay loams furnish a very poor precipitation retention surface, even in regions of light precipitation.

Cultivated soils, particularly light silty loams, are much subject to erosion.

While data for a close quantitative distribution are not available, the approximate ratios of various classes of soils are estimated at:

		Per cent
Loams		65
Clay loams	30	
Sandy and gravelly	10	
Silty	20	
Loess	5	
Clays		20
Sands		10
Gravels		5

CLIMATE

The mean annual precipitation is about 45 inches near the mouth of the Missouri. Westward and northward it gradually decreases to about 15 inches in the upper rolling plains regions, especially in Montana and northern Wyoming. From the edge of the plains the precipitation rapidly increases with elevation in the mountains until at the crests it again attains 35 or 40 inches to even 50 inches or more. In limited areas, noticeably in the Big Horn and the Milk River Valleys, precipitation falls below 10 inches annually.

The basin as a whole might be divided broadly into a humid and semihumid section and a semiarid section, the former comprising

the lower portion of the basin, generally east of a line running through south-central South Dakota to central Kansas, and the latter the remainder, with somewhat heavy precipitation in the small proportion in the mountains. The average precipitation in the humid and semihumid areas is about 30 to 35 inches annually and in the semiarid region about 15 to 20 inches.

In most of the semiarid region a considerable proportion of the precipitation comes in the form of heavy winter snows. The peak precipitation occurs in winter and spring, rapidly falling off in summer and still more in the fall. The winter and spring precipitation aggregates about two-thirds of the total annual, with about half of this coming in the form of rain. In the humid and semihumid region about two-thirds of the precipitation comes in the last spring and summer period with a very scanty winter precipitation.

Material annual and seasonal variations from the mean occur probably about half the time. In one section or another of the basin, especially in the semiarid region, it is not uncommon to have twice the mean annual precipitation for a certain year or period of years or for a particular season. In the semihumid district 50 per cent over normal occurs quite frequently.

In the semiarid region rainfall usually is not sustained for any long period. It comes more in the form of heavy precipitation of a few hours' duration, or showers and cloudbursts. Changes from sunshine to cloud are abrupt even in winter. During the warm season cloudbursts are quite frequent in the central portion of the basin, comprising western South Dakota, Wyoming, eastern Montana, and western North Dakota. In the lower humid and semihumid region rainfall periods are rather sustained, long storms lasting a week or more being not infrequent, although heavy thunderstorms occur in the southeastern end of the basin, as many as 40 or 50 a year.

Temperature conditions vary greatly, based both on latitude and altitude, with latitudinal variations much more dominant. In the upper half of the basin the mean annual temperature ranges from about 38° for the higher elevations to about 45° for the lower; in the growing season these figures are 52° and 62°, respectively. For the lower portion of the basin the figures would run about 20° higher.

Particularly during the growing season the basin is subject to dry, hot winds, more pronounced toward the north than at the southern end. These affect the rolling plains areas much more than they do the mountains. The semihumid section is noteworthy also for its low humidity during the summer period particularly. Only in the lower quarter of the basin are these low-humidity periods not prevalent in the growing season.

These conditions have a direct influence on the evaporation, and hence on surface run-off. The increase in the rate of evaporation is very pronounced from north to south over the basin. In the northern portion the warm season evaporation, as measured in open pans, is slightly more than 30 inches as compared to about 60 inches in the south. Assuming that the pan evaporation is about three times the rate of evaporation from land surfaces on the average over the basin, it is indicated that the rate of evaporation from the soil in the north-

ern portion of the basin is about 10 inches annually and in the southern portion about 20 inches.

In general the winters are quite severe in the northern half of the basin, sometimes with long periods of constant abnormally cold weather, and at other times with rapid temperature changes from day to day. The upper plains region is subject to a very great range, from highs in summer and lows in winter, and is subject also to great diurnal variations. Cool nights after hot days are also the rule in the mountain country, with practically no exceptions.

Practically all the basin is subject to a mean winter (December to February, inclusive), temperature below freezing. But in nearly all the basin, except in the higher mountains, there are temporary periods above freezing which result in winter thaws. A large snow melt in a few hours is often the result. The occurrence of such thaws affects the flood period run-off in varying degrees; in the lower portion of the basin almost all the snow is removed in this way; in the upper portion, especially in the mountains, the effect is much less appreciable, and a very large proportion of the snow remains until the permanent spring thaws.

In the upper portion of the basin the spring thaws either are the primary cause of local floods or augment very materially the run-off resulting from the heavy spring rains. Very appreciable differences in run-off occur one year as against another, as the result of variations in period, intensity, rate, and duration of upward movements of temperature from below freezing point. Records show that a sudden material rise in temperature in the spring is followed by a heavy run-off even though the spring precipitation may have been subnormal. The snow melt, particularly in the mountains, begins in April at the lower elevations, is heaviest in May, decreases by June, and is largely completed at the higher levels in July.

In the northern half of the basin a cumulative effect of all climatic factors is that heavy run-off, especially in the mountain zone, is limited to May and June. In the generally southern half of the basin floods are the result of rainfall which comes heaviest commencing about April; but heavy more or less localized rains occur during the entire summer and fall, and floods on individual tributaries may occur over a more extended period than in the northern half. The central portion of the basin partakes in part of the characteristics of the southern portion in that fall floods are not infrequent in the individual tributaries. The effects of such floods on the main watercourse, however, are negligible, since the storms are localized.

Influence of climate on forest growth.—The broad variations in climatic factors have a distinct influence on forest conditions. The low precipitation, as a whole, in the upper portion of the basin, except in the mountain areas, emphasized by extended dry periods during the growing season, the high temperatures and hot, dry winds, combine to make timber growing in the central plains section of the basin extremely precarious. The result is that as one proceeds up the drainage, natural tree growth gradually diminishes from the heavy more or less uniformly distributed hardwood growth in the southeastern portion of the basin to discontinuous narrow strips along the major watercourses. The timber in these strips gradually becomes sparser and more patchy and scattered in the Great Plains

region proper. A somewhat similar situation exists in regard to the forests which occur at the higher altitudes in the western portions of the basin. The rather dense conifer forests at high altitudes give place to sparse, scattered pine growth of a scrubby nature at the lower elevations, and finally to the broad areas with no tree growth at all.

INFLUENCES OF THE MISSOURI ON FLOODS OF THE MISSISSIPPI

The run-offs from different portions of the Missouri drainage have different effects on the flood stages of the Mississippi. Most of the Missouri run-off has but small influence on the destructive floods of the Mississippi, but the contribution is tangible, and from the lower southeast portion of the basin it has been at times appreciable. It is generally said that floods in the upper Missouri are little feared below the Ohio, but that sudden rises in the lower tributaries give concern. War Department authorities deem that flows of the Missouri above Sioux City, Iowa, have practically no influence on floods of the Mississippi.

This situation, which is well indicated by records of the office of flood control of the Engineer Corps of the United States Army (see Appendix III) leads to the conclusion that under existing conditions it is the flood flow from roughly the agricultural belt which can be considered as of most importance in Mississippi floods. Unquestionably this has always been true, because of physical conditions, irrespective of man's influence in changing those natural surface conditions which affect period and rapidity of run-off. Proceeding down the Missouri River, it is obvious that the tributary basins, and hence the major watercourse itself, would have increasing influence on the Mississippi floods. This is the result of two unchangeable physical factors. First, the lower portions are much closer to the Mississippi and consequently high flows here are sooner reflected in that stream, and also are more definitely reflected, since the main river channel has not enough length to provide a storage area large enough to smooth off sudden crests. Secondly, much heavier precipitation, annually, and for protracted periods and the readily erodible and generally less moisture retentive soils favor rapid and heavy run-offs.

But, as will be shown later in this discussion, man's influence in the lower portion of the basin has on the whole been such as to enhance materially the natural tendencies for rapid run-offs which affect Mississippi flood stages, whereas in the upper portion of the basin injurious influences in this regard have been of much less degree. Were the upper portion to attain a similar degree of injurious condition undoubtedly its influence would be more unfavorable. It is not so true then that conditions in the upper portion of the basin can be disregarded entirely. There is that constant normal flow from here that must always be taken care of by the Mississippi. At present its effect is small. But if the injurious influence from here is enhanced the effect may become much more appreciable. Flood-control measures which will provide for only present normal flows from the upper basin would be inadequate if such normal flows were increased. Also, any possible decreases in the normal flows from the

upper basin would at least increase the factor of safety. The run-off of the Missouri as it affects the Mississippi presents then not only a major problem of improving conditions in the lower Missouri, but also a secondary problem of at least continuing all favorable natural surface conditions in the upper portion of the basin.

DIVISION OF BASIN INTO BELTS

Moisture factors are undoubtedly the prevailing influence in the variations of natural conditions, and as a consequence the cultural development of various portions of the basin. The basin thus has a natural division roughly into a forest belt, a grazing belt, and an agricultural belt.

The forest belt consists practically of the mountainous rim at the western edge of the basin and the mountain outposts where pine forests naturally occur. It comprises about 6.5 per cent of the area of the basin, or about 35,000 square miles. The grazing belt is the region in which the predominating land use is of the forage. It includes about 45 per cent of the area of the basin, or about 235,000 square miles. The agricultural belt comprises a region in which cultivated farm crops are the principal product. It covers about 48.5 per cent of the area of the basin, or about 255,000 square miles. The boundary between the agricultural and the grazing belts follows roughly the edge of the 15-inch growing-season precipitation through western Kansas, central Nebraska, central South Dakota, and western North Dakota. These belts have no distinct limits; they shade into each other.

Within the forest belt is an appreciable area of nonforest lands, about one-third of the region, which is used predominantly for grazing. Agriculture, which here is limited in extent, is subordinate as a rule to livestock production.

The grazing area is comprised mostly of unfenced range and large fenced pastures. A small aggregate acreage is under cultivation, and there are practically no forests as such. However, about 10 per cent of the area has scattered scrubby tree growth of coniferous species or is in the flood plains of the major streams, with light to dense growth of hardwood species.

The agricultural belt is estimated as having about 55 per cent cultivated, about 42 per cent in fenced pasture, and less than 3 per cent in forest, entirely hardwoods, almost wholly in wood lots, except for a relatively small area in Missouri.

HISTORICAL DEVELOPMENT

Originally the natural cover in the greater portion of the agricultural belt was generally of plains long grass character with a considerable portion in hardwood forests. The prairies were intersected by strips of hardwood timber along the watercourses, which were more frequent, denser, and wider toward the semihumid areas in the lower portion of the basin, becoming solid areas of timber interspersed with scattered parks, and on a small area changing to pine. The timbered areas gradually dwindled toward the north and west, where they were confined to the flood plains and ultimately occurred as sparse scattered patches.

The grazing-belt country was typified by a short-grass cover, with sagebrush predominant on the heavier soils and practically no cover in the Bad Lands areas except sparse grass along the draws and coulees. Scattered tree growth occurred in restricted localities, principally of poor quality yellow pine with some scrubby juniper. In a few places these areas were dense enough in stocking to justify classification as woodland, but even here the predominant cover was herbaceous vegetation.

The timbered belt contained dense stands principally of lodgepole pine and some Englemann spruce in the higher elevations, gradually giving place to stands of yellow pine and Douglas fir at the lower levels. The valleys intersecting the mountain areas resembled the grazing belt with natural cover mostly of the short grass, but also with some long grass and some sagebrush.

The development historically will be discussed separately for each belt.

Agricultural belt.—The earliest settlement began about 1820 in a small district near the mouth of the Missouri. About 1825 agricultural settlement began generally in the southeastern portion of the basin; it rapidly spread northerly, settlement in the Dakotas beginning about 1830. By about 1870 to 1880 considerable activity spread westerly toward and into the grazing belt and toward the mountains.

Local moisture factors influenced direction of development, which was limited in the drier districts at first to stream valleys and subirrigated lands, and to a certain extent by the availability of timber for fuel and building material. With periodic setbacks due to series of drought years development increased steadily, especially since 1900. The original sod cover has been gradually broken up and more and more land converted into farm-crop production.

Currently with agricultural development the original timber stand was removed. Most of such clearing was to provide room for farm crops, especially in the districts having the greater extent of forest growth; everywhere concurrent with this was the utilization of timber products primarily for local use. As the proportion of forest dwindled toward the more arid north and west an increasing proportion of the cutting was for timber products.

By and large, but little of the originally heavier forested portions now remain in forest. This is comprised almost entirely of wood-lot remnants of the original timberlands, and to less degree of shelter belts and wood lots planted subsequent to agricultural development. Relatively only a small proportion has been cleared toward the north in the Dakotas, and broadly speaking, the lower down in the drainage the greater is the proportion of the original forested area that has been cleared.

The effect of development has been to increase erosion and run-off in considerable though varying degree. Most distinctly this has occurred on the lands under cultivation, in places especially where "open" crops are planted on the loess and silty soils and where no special attention has been paid to erosion factors. Wind erosion also has been augmented, increasing the silt burden of flood waters through the deposits of wind-blown material along the stream course. The woodland areas which generally are grazed, and the pasture areas, have as a rule been overgrazed, with the result that the protec-

tive sod covering has lost much of its beneficial virtues. These injurious effects have cumulatively affected the flood situation on the lower Mississippi, but also distinct injuries are felt by the owners of the lands concerned. This has been recognized by various extension agencies which have been for some time considering ways and means for betterment. Clearing of river-bottom lands to the edge of the stream banks has encouraged bank erosion, speed of flood flow, changes of river bed, and wash of the surface of the flood plains. Heavy cutting on some of the "breaks" too steep even for good grass stands has not always been followed by a cover which has retarded run-off and erosion.

Grazing belt.—The first general utilization of the resources was in the form of vast cattle herds using the abundant grass, summer and winter. This had no effect on erosion and run-off, since overgrazing was extremely limited.

Farming settlement began about 1880 to 1890 and followed generally westward up the main watercourses and along the railroads. The richer, more easily worked soils in the alluvial bottom lands were broken first. Aside from wind erosion, this type of soil is not subject to appreciable erosion either in its natural state or under cultivation. About 1900 to 1910 dry farming became appreciable on the higher, rolling prairie lands, particularly in the plains of the northern half of the basin. Farther south in the semiarid region, irrigation accompanied farming development to a much greater degree. The soils thus put to use were not of the kind that readily succumbs to water erosion. About 1914 to 1918—the war period—considerable expansion in dry farming took place particularly in Montana and the Dakotas. Submarginal soils were broken up, much of which are of the readily erodible character. After a few years these lands were abandoned, but the sod-holding grass cover had been destroyed. It is now gradually returning, the more slowly the heavier the soil. The most economic and profitable use of these soils is for grazing; properly regulated grazing will result in better erosion and run-off conditions.

Some bottom-land clearing for agriculture has taken place in the wooded plains of the major watercourses. Also, particularly in localities neighboring to settlement, some of the bottoms were cut off for fuel. In some localities having sparse yellow-pine growth there has been liberal cutting for timber products. Cutting the hardwood timber along watercourses, close to the river banks, removes in varying degree its influences against the cutting away of river banks and the washing away of soil from the flood plains, and for slowing up the current. The cutting in the pine type is practically of little consequence on erosion and run-off, the grass being the dominant herbaceous cover.

The development of the country has had its greatest effect upon the herbaceous vegetation. The early cattle herds generally did not overgraze, but as cattle and sheep herds increased and more land was put to other uses a greater burden had to be carried by the open range. A number of localities exist where unwise grazing utilization has injuriously affected the natural influence of the original grass cover in retarding erosion and run-off.

Timber belt.—The first development in the timber belt was principally in connection with mining, in the sixties. This was localized

in the mountains of Colorado and southwestern Wyoming and in a number of sections in Montana. Activities continued high for about 30 or 40 years and still persist. Mining in the Black Hills commenced about 1875 and was very active until about 1910, and still continues on an appreciable scale.

In the earlier periods of activity uncontrolled forest fires were rather common, especially in Colorado and Wyoming, and as a general thing clear cutting of fair-sized areas took place. On the whole the damage was not permanent, reproduction becoming generally reestablished except on repeated burns or heavy cutting followed by burning. Exceptions occur on a number of areas aggregating about 210 square miles in Colorado and Wyoming. Also in the vicinity of Butte, Mont., on areas negligible in size, denudation of originally rather thin stands at high altitudes is complete as a result of cutting, fire, and smelter fumes. On the whole practically no erosion has resulted, though there was and is a definite depreciation of the run-off and snow melt retarding influences of these areas.

After mining, the next general utilization was by the grazer in the valleys between the timbered mountains. Agriculture followed, originally in providing winter feed to supplement the summer range. The utilization of the untimbered portions of the timber belt was much like that of the grazing belt.

On the whole lumbering has not made any appreciable difference in the natural cover of timber. Exceptions exist in very localized areas in the vicinity of the mining country in Montana, in the vicinity of heavy settlement in Colorado, and in the Black Hills. The amount of cutting for entirely local use in the vicinity of the smaller settlements is negligible.

By and large, the distribution of forests and grass lands in the timber belt remains just about as it was before the coming of the white man.

Broadly stated, for the basin as a whole, the effects of the removal or reduction of the natural tree and grass cover, through clearing in connection with cultivation in the lower Missouri region; through unregulated and unwise grazing in the grazing region; through unwise overgrazing in the wood lots and pastures of the agricultural belt; through limited careless burning in parts of the mountain region and in small portions of the pine area in Missouri; and through methods of cultivation which in the past gave no consideration to reduction of erosion and run-off, have been injurious and gradually cumulative. Erosion affects rapidity of run-off, since as it progresses, so progressively more and more of the run-off retarding vegetation is depleted or destroyed.

CONDITION OF AREAS OTHER THAN FOREST LANDS

Improved lands.—Cultivated areas in the forest belt are confined to lands originally nontimbered, almost entirely in the flood plains and the valleys at the lower elevations. Crops are practically all hay or small grains and the latter almost wholly wheat. The steeper soils are, as a whole, not cultivated. The effect, therefore, on erosion and run-off is negligible. In limited localities there is wind erosion.

In the grazing belt the principal crops on the improved lands also are hay and small grains with a rather heavy proportion in wheat.

The proportion of small grains and "open" intertilled crops like corn, increases toward the limits of the agricultural belt. The effect on run-off and water erosion is here also not very material. Wind erosion is by far more important, since it is the cause of an appreciable contribution to the silt burden of the water courses. It is estimated that about 25,000 square miles are under cultivation of which about 30 per cent is in hay, 50 per cent in small grains, and 20 per cent in "open" crops.

In the agricultural belt there is a predominant proportion of intertilled "open" crops with corn as a major product. This character of cultivation progressively increases toward the southeastern end of the basin where it reaches as high as 45 per cent of the total cultivated area. Over the greater portion of the "belt," water erosion and run-off are not serious, but in the lower part of the basin, especially on the steeper clay soils, or on the rolling loessal soils particularly, and where forest land has been cleared for farming, erosion is enormous. In some localities fields have been abandoned because of erosion. The principal of these areas is in the vicinity of the main Missouri River in Nebraska, and from there down to the mouth in eastern Kansas, and in practically all of Missouri.

Toward the southeast end of the basin the proportion of pasture land which has been developed, as against natural pasture, increases; this kind of land is usually overgrazed.

Throughout the agricultural belt wind erosion is material.

In the agricultural belt there are roughly a little under 100,000 square miles under cultivation, roughly estimated at 25 per cent in hay, 35 per cent in small grains, and 40 per cent in "open" crops.

The variation in influence of different kinds of crops on erosion is considerable. No figures are available conclusively to represent all conditions in the drainage. But figures [3] prepared from results of experiments carried on in Missouri give evidence that erosion is far greater from "open" crops than it is from hay or grass land. Ordinarily it is judged that forest cover is better even than hay land, and always is at least as good for resisting erosion.

Of the total area of crop land in the Missouri drainage, estimated at about 125,000 square miles, about one-fourth is in hay and other grass crops, about one-half is in small grains, and about one-fourth is open crop. Improved land used for pasture aggregates about 15,000 square miles.

[3] Average annual erosion of silt loam soils of northern Missouri under different degrees of slope in different crops:

Kind of crop	Tons of earth eroded per acre a year from a slope of—		
	2 per cent [1]	3.68 per cent [2]	4.2 per cent [1]
Corn in rotation with small grain or sod	1.63	3.27	4.47
Corn following corn	12.63	25.26	34.60
Soy beans or cotton	10.05	21.00	28.77
Grass or clover	.12	.24	.33

[1] Variation for different degrees of slope computed by W. W. Ashe.
[2] Experiments covering 7 years conducted by Dr. F. L. Duley and M. F. Miller in northern Missouri.

Unimproved lands.—Unimproved nonforested lands in the forest belt and in the grazing belt consist largely of open range, principally in the northern portion of the basin, and of large fenced pastures whose owners are nonresident. Here are a number of extensive areas known to be heavily overgrazed. An incomplete record shows at least 15,000 square miles in this category. Overgrazing, particu-

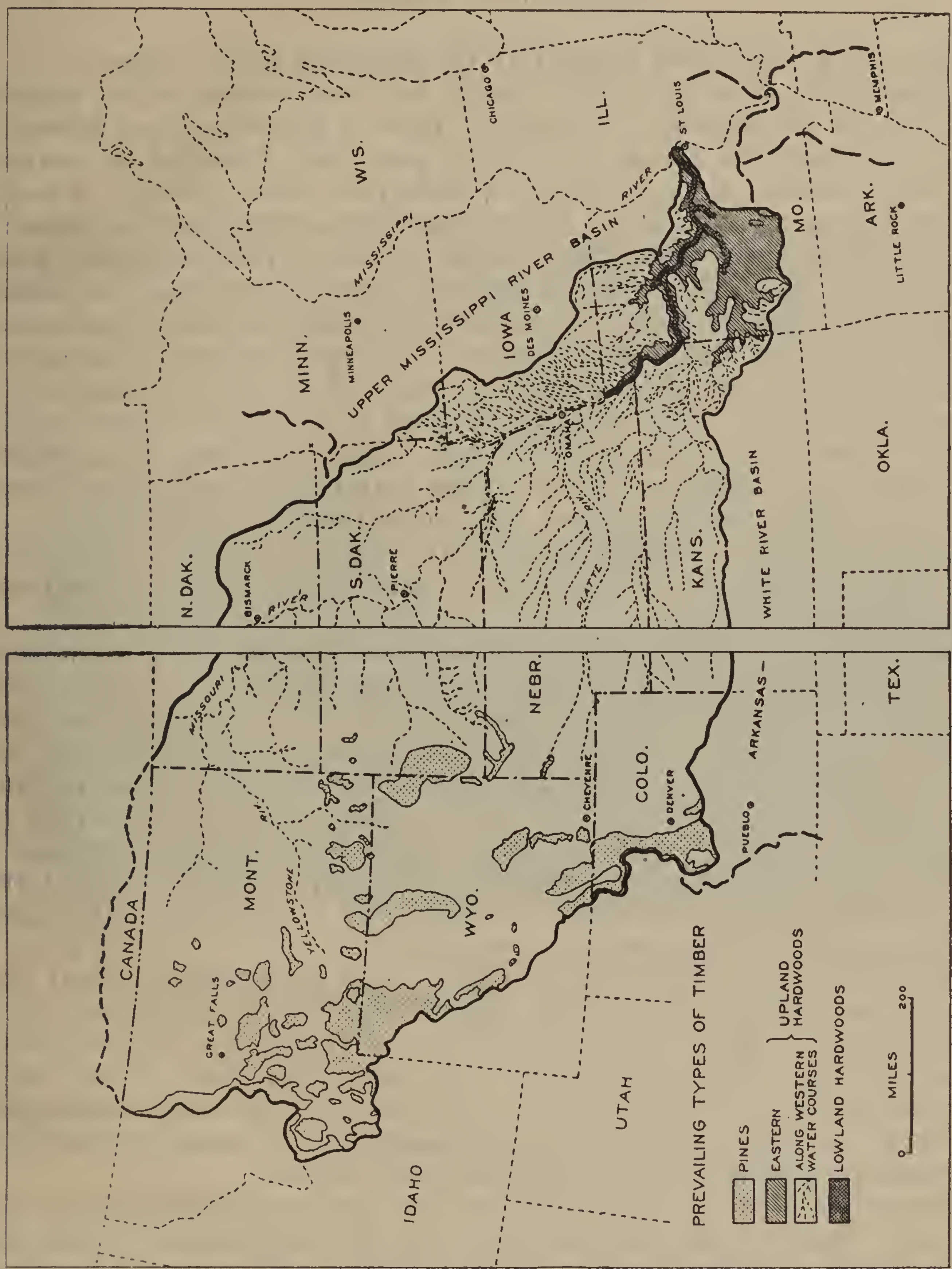

FIGURE 3.—Missouri River Basin

larly on clay soils and on the steeper ground, results in the depletion of the vegetative plant growth and sod cover together with a decrease of the proportion of the palatable perennial grasses which bind the soil and an increased proportion of the less palatable annual weeds which have much less soil-binding virture. Erosion on such tracts both from wind and rainfall is quite material and run-off through the decrease in the sod cover is distinctly increased.

In the agricultural belt the unimproved nonforested lands are mostly farm pastures. As a general rule, these are overgrazed. They occupy principally the steeper lands, not desirable for cultivated crops. As a result, there is considerable erosion, particularly in the clay, clay loam, and loess areas.

CONDITION OF FORESTS

This will be discussed separately by the three major belts.

Forest belt.—Forests in the forest belt are comprised of rather dense stands principally of lodgepole pine or spruce, giving place at lower elevations to stands of yellow pine and Douglas fir, which gradually become more sparse and disappear lower down. An exception occurs in the Black Hills, where practically all the timber type is yellow pine and Black Hills spruce. The lodgepole pine forests are composed of pure lodgepole stands to mixtures of about 80 per cent lodgepole pine, 15 per cent Douglas fir and Engelmann spruce, and 5 per cent other species. The spruce type is composed of about 85 per cent Engelmann spruce and 15 per cent lodgepole pine and alpine fir. The Douglas fir type is principally Douglas fir, about 10 per cent being white fir and lodgepole pine. The yellow pine type varies from practically pure stands to as much as 50 per cent Douglas fir and scattered lodgepole pine. The mountains in the upper tributary basins run mostly to the lodgepole pine type, while those in the lower tributaries carry principally the spruce type.

Except in the general vicinity of large settlements, such as mining centers, cutting on the whole has not been extensive. It has been practically negligible in the forests of the upper tributaries and has been heaviest in the relatively more densely populated areas in southern Wyoming and Colorado. On the whole, cutting has not been injurious, though severe in places. Reproduction is coming in everywhere except in limited areas where repeated fires have followed cutting. Small localized areas close to mining camps have been stripped and reproduction in such spots is sometimes light, but in the aggregate these spots are negligible.

The effect of peat fire is now slight. Less than 2 per cent of the timbered areas has been burned over in the last 20 years, and it is certain that the figure will be much less in the future except where reasonable protective arrangements are not established. Generally, reproduction has followed burns. In only one tributary drainage, the Platte, is there any area of consequence that needs replanting, an estimated aggregate of about 210 square miles.

The timber growth in these forests has not been affected by grazing use. Most of the forested area is under National Forest or Indian Service administration, which assures well managed grazing use; and while unregulated grazing is very liable to injure the herbaceous vegetation, it does not appreciably affect trees or reproduction. The handling of privately owned lands within national forests has been considerably influenced by the handling of the surrounding Government lands. Grazing on the small proportion of timbered lands outside of Federal reservations is somewhat more

FIGURE 2.—Taylor Fork, Gallatin National Forest, in July. A critical area of beneficial influence. Above timber line in the high mountains snow melt is delayed by altitude; below, the dense forests retard snow melt earlier in the season and delay surface run-off from spring rains

injurious, but is not material because of the small aggregate area involved.

In general, forest areas in the timber belt are in good condition. The forested area is almost coincident with the extent of forest growth found by the white man.

Grazing belt.—In the grazing belt tree growth is of two kinds. The pine type is composed of scattered patches of generally sparse scrubby individual trees, principally of yellow pine. There are occasional small patches of denser growth where moisture and soil conditions are locally more favorable than the average. Most of these areas can scarcely be called forests; indeed the descriptive name of woodlands is scarcely applicable to a good portion of them. Rather could they be described as scattered, scrubby-tree occurrences on grazing lands.

The hardwood type occurs along the larger stream courses in the form of narrow interrupted spotty strips on the flood plains and as patches along the lower portions of draws and coulees. The species are principally cottonwoods, ash, aspen, box elder, elm, and various shrubs.

The pine type on the whole is not seriously affected by lumbering. There is some localized cutting for fuel and farm improvements. Such cutting, while it has in places decreased the number of trees on the area, does not really injure the moisture and soil retention benefits of the cover. This is because the influence of the trees scattered as they are is practically negligible anyway, and the grass growth merely extends and covers the spots where theretofore trees interfered.

In the hardwood type but little cutting has occurred in the northern portions of the basin in Montana, Wyoming, and the Dakotas. Lower down, at the edge of the agricultural belt and in a transition zone, appreciable areas have been cleared for agriculture. On the whole, clearing by man either for cultivation or in connection with the removal of timber products has not been great.

In neither the pine type nor the hardwood type has there been appreciable burning. A theory exists that prairie fires in past decades have prevented any material spread of pine reproduction, and that this spread is now occurring with the reduction of prairie fires. There is insufficient certainty in such an idea to serve more than to indicate a possible line of investigation.

In neither type has there been any appreciable effect on forest species as the result of grazing.

On the whole, both the pine type and the hardwood type in the grazing belt are just about in their natural condition. Whether natural conditions can be improved is doubtful.

Agricultural belt.—In the agricultural belt the forest comprises practically the wood-lot remnants of the original central hardwoods type, to a lesser degree planted shelter belts and wood lots established since agricultural development of the country began, and a small area of lumber woods pine type.

Lumbering has lowered the quality and density of the forest stands. This has resulted in a decrease in the beneficial effects of the cover, principally on erosion, but also on run-off.

Practically no fires occur, except in connection with grazing use.

Probably the greatest injury to this land results from grazing. This injury is partially to the tree species, in reducing quantity and strength of reproduction, but mostly to the soil itself in that heavy overgrazing is the rule. An indirect injury is the burning, with the idea of improving grazing, that occurs very locally in Missouri.

There has been practically no drainage of wet areas. Small areas along the Missouri River's flood plains have been cleared and drained and put under cultivation. The effect is not on the timber so much as on speeding the flood run-off, but the latter is negligible in effect on the Mississippi.

Generally, these wooded areas are much depreciated from their natural state. This comes from unintelligent cuttings and from overgrazing. It has an injurious effect on erosion principally, and on run-off.

CRITICAL AREAS

The outstanding critical areas of detrimental influence are the Bad Lands, and with them the heavy clay soil areas in various degrees of erosion which have not yet reached the bad land stage. These are situated in the semiarid region and in the grazing belt. The alternation of desiccating winds and weather, with heavy concentrated rainfalls, has been very effective in causing soil wash. The effect of these areas is distinctly detrimental; the run-off from them is very rapid. These areas are rather widely distributed. The Bad Lands proper occur in southeastern Montana, southwestern North Dakota, and western South Dakota in rather large bodies. The bad clay areas are generally situated along the breaks of the major watercourses in the same three States and in Wyoming.

These areas have an herbaceous vegetation, varying from sparse to none at all in the worst portions of the Bad Lands. In a few localities there is sparse tree growth occupying the sites most favorable as to protection from wind and presence of soil moisture. By and large, the timber is so scattered that it is of little consequence in reducing run-off or preventing erosion, but within the general Bad Lands and heavy clay areas there are occasional small districts of somewhat denser timber, where topography, soil, and moisture conditions favor such growth. This timber brings about a measure of beneficial influence, since it helps reduce run-off and holds the soil. The only present utility of the detrimental Bad Lands and other heavily eroded clay areas, which fades to negligible in the worst of them, is grazing. As a general rule, improperly managed, uncontrolled grazing, has depreciated materially such beneficial effect in retarding run-off, and binding the soil as the sparse vegetation may have had. Whether part of the public domain or whether privately owned, nothing is being done to improve the condition of these lands.

Another group of critical areas of detrimental influence is comprised of the overgrazed unimproved open range lands. In the grazing belt are several units, of clayey loam soil, which, though not so readily erodible as the Bad Lands and heavy clays, nevertheless have had their protective vegetative cover so seriously depleted, that erosion is now beginning or is well advanced and with continued

abuse of the lands, promises to increase to serious proportions. Erosion progressively reduces the vegetation and the chances of its recuperation; as a result, virtues of the vegetation in retarding run-off are progressively decreased. In addition to these areas in the grazing belt are similarly overgrazed range lands intermingled with the

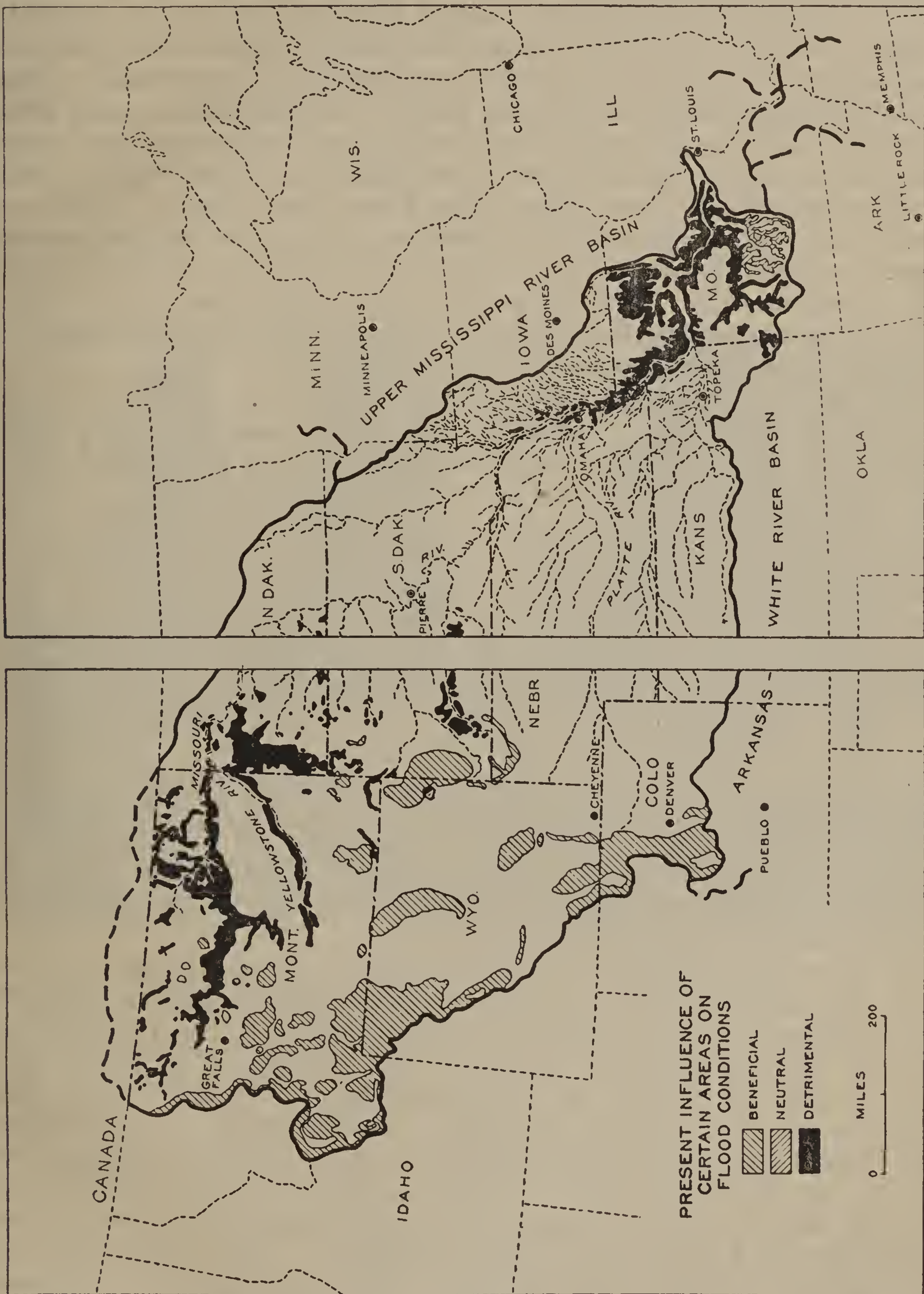

Figure 4.—Missouri River Basin

forest areas in the timbered belt. These lie outside the national forests and national parks. An appreciable portion of all these overgrazed range lands is public domain apparently not sufficiently attractive to be acquired under the land laws. Legislative action of one sort or another has been urged to provide for control of the grazing use, but little has so far been made effective.

A great portion of the whole area in the agricultural belt is critical with a detrimental influence. As a rule, the wooded areas occupying the steeper ground have easily erodible soils. Deterioration of the forest cover and overgrazing of the vegetation underneath are cumulatively increasing erosion from these tracts and reducing their influence in retarding surface run-off. These tracts are in a vicious circle; as the lands deteriorate, their forest and herbaceous cover depreciates; as the forest and vegetable growth depreciates, the land deteriorates. The fenced pastures are generally overgrazed. Often the soil-binding grasses are giving place to unpalatable annual weeds which have a far less capacity for binding soil and retarding run-off. Under these conditions the heavy precipitation of the region results in increasing erosion year after year from these tracts. These evil effects are enhanced because the pastures occupy the steeper ground. A great proportion of the lands under cultivation have loess or other easily erodible soils. A large part of the cultivation is to "open" crops. As a result, erosion is vast. As everywhere else, erosion is an index and a cause of decrease in retarding run-off.

Until recent years not much thought has been given to erosion from the lands in the agricultural belt. Agronomists in the extension services and foresters are increasingly giving the subject attention. Primarily for the benefit of the individual owner of these tracts, more careful use of pastures and special methods of cultivation and special practices in crop rotation are being urged; extension of woodland planting is being recommended. It is to be noted that in practically all classes of critical areas in the agricultural belt, in which conditions for retarding erosion and run-off are not at their best, the lands concerned are also not producing the most of potential returns to their owners. Erosion in cultivated fields reduces their crop production. Pastures and range lands which are being overgrazed progressively decrease in carrying capacity. Wood lots which have been abused produce less timber material and if overgrazed continuously decrease in forest-crop production. It is clear that it would on the whole pay owners to handle these lands better for their own immediate benefit, and that the benefits of controlled run-off and erosion would follow incidentally.

The principal beneficial critical areas are the rather dense forests within the national forests and the national parks and the relatively small aggregate area of timbered lands scattered in the Indian reservations or privately-owned or part of the unreserved public domain. These lie almost wholly in the timber belt. On the whole these forests are in good natural condition. Their influence is beneficial; they retard the rapid spring melting of snows and help decrease the rate of run-off from rains. In the national forests and national parks general provision is made and organizations are available for maintaining and improving forest conditions. To a less degree the same is true of Indian reservations. The small areas of timbered lands outside the national forests and usually integral parts of them, quite often unreserved public land, have no assured protection or administration. However, such timbered areas are generally of the woodland lightly-timbered type, which makes the timber less of influence than where the forests are denser, and are located at the lower elevations where less precipitation and higher temperatures cause less concentration of snow melt to augment the spring rains.

FIGURE 5.—Hayden National Forest, Wyo. A direct northerly exposure. The timber retains snow banks in its shelter long after the snow has disappeared from the open land thereby delaying run-off

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FIGURE 6.—Near confluence of Bear Creek with Platte River. Timber along stream bottoms help to preserve the banks, bind the soil and prevent injurious gravel and silt deposits. When the timber is removed its beneficial influence is lost. (Two views)

In southern Wyoming and Colorado in the grazing belt are a number of small areas of forested land whose beneficial effect is in jeopardy from overcutting or from fire. A large proportion of these lands is public domain. No agency is responsible for improving or maintaining these lands in good condition or preventing their injury.

The hardwood areas along the watercourses in the grazing belt are considered critical particularly as to a fringe along the banks of the streams. The influence of these hardwood areas is mainly beneficial and partly neutral. No great degree of cutting is being done but such as occurs is without consideration of the effect on the lands concerned or of control of floods on lands below.

Roughly the extent of critical areas by classes is as follows:

	Square miles
1. Critical forest areas, pine type, practically all beneficial	22,000
2. Critical forest areas, hardwood type, about one-half beneficial and one-half neutral	9,000
3. Critical overgrazed grazing areas (incomplete record), detrimental influence	15,000
4. Bad Lands, detrimental influence (clay lands detrimental and neutral, not possible to estimate)	15,500
5. Critical farm areas, mostly in lower portion of agricultural belt on the steeper land, detrimental influence, a rough estimate (based in part on extent of "open" crops)	35,000
6. Critical farm pastures, detrimental influence, a rough estimate	20,000

RECOMMENDATIONS FOR CRITICAL AREAS

In practically all cases the proper handling of the critical areas to provide the most beneficial run-off and erosion conditions is nothing more than is advisable to make the most economic use of the land and its products. Consequently, rather than primarily for flood-control purposes, practically all of the recommended steps are desirable irrespective of flood control.

To the above there is one outstanding possible exception. A Federal Government function in addition to the activities being carried on under established policies in connection with national forest and similar wild lands—and a direct function desirable from the standpoint of flood control if for no other reason—concerns itself with the Bad Lands. Their detrimental influence is due primarily to the scanty cover, clay soils, and localized torrential cloudbursts.

The only change that man can possibly make in the three factors of soil, rains, and cover is in regard to the last—cover. It is a moot question whether anything practical can be done, and the preponderance of qualified opinion is apparently in the negative. Generally these opinions agree that any attempt to revegetate enough to have any effect would be very expensive and of doubtful permanence. At best it would be a tremendous undertaking. However, the great influence of these areas and the possibility that something might be found feasible are sufficient to justify making the project a matter of special research. Heretofore consideration of revegetating these areas seems to have been most often based on having them produce remunerative crops. The major objective should be erosion and run-off control and it is possible that, after all, some crops of an economic value might be produced.

The following recommendations provide for steps primarily desirable for purposes other than flood control, but flood-control benefits will be incidental.

Critical forested areas in the timber belt.—Established Forest Service practices on national forest lands should be continued. Similar sound progressive practices should be extended to other lands. This includes protection from fire, insects, and other injuries to the maximum degree justified from the standpoint of long-time economics. It includes the extension of planting of denuded areas not reproducing naturally to a minimum satisfactory degree from the standpoint of long-time economics. It includes the regulation of cutting in forest stands so as to leave the cut-over areas in the best shape possible for the continued production of valuable timber, so far as expense is justified from the standpoint of long-time economics.

Measures necessary to attain these results involve the State governments as well as the Federal Government. These include further development of the established means, directly and through cooperation with various agencies, for the protection of the lands from fire, insects, and other injuries. They include also the adjustment of national forest boundaries to add certain areas of public domain which are integral parts of the national forests, or certain blocks of timberland now mainly privately owned, which are not now integral parts of existing national forests, where it is feasible and economic for the Federal Government to take over control; they include the acquisition by the Government of privately owned lands within existing national forests. They include the continuance of policies concerned with the planting of denuded lands not naturally reproducing, with a cover which will produce crops of greatest economic value, and incidentally improve run-off and erosion conditions. They include the stimulating of the protection of privately owned and other forested lands through the means provided in the Clarke-McNary Act. They include the stimulation of good forestry practices by private owners. They include the enlargement of State activities in developing State forests and parks.

Critical range lands in grazing and forest belts.—Some means should be provided for lessening the evil results of uncontrolled grazing. The problem is complicated in many respects, chiefly by diversity of ownership of such lands. A careful study should be made of feasibility of control. Considerable scientific and economic information is already available through the National Forest Service and cooperative agencies as to how best to utilize the range lands under varying conditions in various parts of the region. This knowledge should be applied as far as feasible.

Measures to attain these results would include consideration of ways and means of putting the public domain land under some form of administration; and education by the various extension services in the proper handling of privately owned range lands. There might be included certain regulatory State laws, such as herd laws, which may be found feasible and constitutional.

Hardwood strips along major river courses in the grazing belt and upper portion of agricultural belt.—The value of timber stands along river banks to retard caving, in reducing the amount of bank change, and in ameliorating the effect of flood waters on the proximate lands

in washing and in injurious silt deposits may be continued in many cases at less cost than the building of special revetments after the timber has been removed. Exceptions would occur in highly valuable potential farm lands, especially in the lower half of the basin, but even here, often a narrow fringe along the stream could be beneficially left.

Results would be obtained mainly through education of private owners.

Wood-lot areas in the agricultural belt and the lower grazing belt.—Wood lots and woodlands along streams should be protected and enlarged. West of the ninety-ninth meridian—roughly western Kansas and Nebraska, and west and north of that—it is deemed justifiable to have at least 5 per cent of each farm in wood lot; justified from the standpoints of land economically unsuited for more profitable crops and of furnishing the farmer with timber products, with protection from wind, and with protection from erosion at critical points. Elsewhere in Kansas, Nebraska, Iowa, and Missouri where there is a large proportion of cultivated readily erodible soil, more productive land, increase precipitation, and less care needed of timber tracts, it is probable that 10 per cent of each farm could justifiably be kept in wood lot. In the region originally timbered with central hardwoods, roughly the eastern portions of Nebraska and Kansas and along the Missouri River in Missouri, where physical factors arguing for wood-lot extension are emphasized and augmented by distinctly heavier precipitation, as much as 20 per cent of each farm in wood lot appears justified.

Factors in this objective would comprise work by extension agencies in educating the landowners concerning benefits to be derived directly by them; they would comprise expansion of State forestry work, including increased efforts along investigative lines and increased provision for furnishing forest plantation stock at low cost. They would include meeting on common ground and coordination of efforts by extension foresters and extension agronomists, so that existing conflicting recommendations may be adjusted.

Farm-pasture areas.—Unwise pasturing of these tracts should so far as feasible be reduced.

This would comprise the assimilation by extension agencies of the knowledge so far developed concerning best practices in handling pasture areas and the dissemination by them of this information among landowners, so that they may know the distinct advantages to them of continuing pastured areas in a highly productive state.

Agricultural areas.—Good management and protection of agricultural lands require the proper selection and alternation of crops, the proper cultivation methods including fallowing and kinds of plowing, and the terracing of lands of high productiveness on steep slopes, and other mechanical means such as brush dams in draws. These practices are desirable primarily to obtain the greatest yield from agricultural effort, and to decrease the deterioration of these lands through loss of fertility through wind erosion on all classes of light soils and water erosion on lands other than flat. Benefits as to flood run-off would come incidentally. These ends would have to be attained through education by extension agencies.

A part of the agricultural land problem involves the attempted cultivation of new lands which are submarginal either because of character of soils, or of steepness of the ground, or too low fertility to justify the expense of terracing, or a combination of these. The cumulative effect on flood control, in addition to economic loss of human effort through abandonment of fields found to be unsuited for permanent cultivation, has not always been recognized. To avoid this would require a more careful classification of public lands now open to farming entry, and education by extension agencies on the selection of privately owned lands for cultivation.

ESSENTIAL MEASURES TO KEEP FOREST LAND PRODUCTIVE

The area to be kept in forest comprises about 31,000 square miles of critical forest area. To be added in the lower Missouri in woodlot extension are roughly estimated an additional 5,000 to 6,000 square miles.

The measures to accomplish the objectives for forest lands particularly that have already been recommended are below summarized more specifically by classes:

Forest protection.—The practices already established for protection from fires should be continued and intensified. This is primarily a measure for the Forest Service and its cooperating agencies, since the chief menace of fire is in the timbered belt. There is needed a stabilization of the Government's protection policy on forested areas in the public-domain lands. At present, though protection is furnished, it is not definitely established as a policy, but is dependent wholly on appropriations from year to year, and it is not as intensive as that provided for the national forests and the national parks.

Control of the ravages of insects and forest-tree diseases needs considerable development of scientific knowledge and a stabilized policy in providing funds for accomplishment of the necessary work. Under present conditions insect-control work has often been subject to loss of valuable time while waiting for special legislation and appropriations. Control of tree diseases is dependent entirely on expedient opportunities furnished in connection with Forest Service timber sales.

Forest planting.—The Government's forest-planting program for the national forests should be continued and stimulated. For example, the 210 square miles needing planting in the Platte drainage should be planted as quickly as possible—in 25 years if feasible. Federal cooperation should be extended under the Clarke-McNary Act to provide planting of wood lots and shelter belts. This will involve increased appropriations on the part of both Federal and State Governments for the furnishing of low-cost forest planting stock. It would involve additional nursery capacity, particularly by the States. Among other steps this program would require the appointment of a State forester in South Dakota and the increase in capacity of Federal and State nurseries.

Public acquisition and national-forest additions.—Additions should be made to the national forests of similar lands now outside the boundaries but integrally a part of existing forests or which under existing national-forest policies can be made logical parts of such

forests.[4] This would include public-domain lands, particularly those lying adjoining or near the national forests, and intermingled private lands which could be acquired through exchange. It would include the acquisition through land exchange of most of the 2,900 square miles of privately owned land within the existing national-forest boundaries.

The several States should acquire as parks or forests tracts too small for Federal control and economically not feasibly protected or administered privately, or the handling of which primarily to decrease erosion and run-off would be uneconomic to private owners. This would be primarily a State activity involving further careful consideration and investigation, and would be applicable chiefly to that portion of the basin embraced in Missouri, Iowa, and eastern Kansas.

Investigation and research.—Investigation and research have a prominent place in a progressive program. A study should be made of the possibilities through special planting and through the control of grazing of improving soil erosion and run-off conditions on the Bad Lands and the bad clay lands, which even in natural state are in danger of becoming or have been seriously eroded. A large part of these lands are public domain lands and of no known or practically negligible economic value if privately acquired; consequently the problem appears to be one entirely belonging to the Federal Government.

Findings and recommendations for handling privately owned farm wood lots and similar lands are now being made by divers investigative agencies in the States and often are conflicting. Coordination is necessary. This would include correlation of the studies and recommendations of the various sections of the State agricultural colleges and extension services as well as closer correlation between these and the Federal Department of Agriculture. It probably would require careful joint investigation in the form of a partial or complete farm survey by various State and Federal agencies in cooperation.

Increases will be necessary in Federal and State Governments' contributions to investigations affecting forest growth and other economic forestry factors, especially on privately owned wood lots.

Educational work.—Educational and advisory work should be extended. All of it should be closely coordinated. This should be possible through the various agencies getting closer together in their investigative work and in correlating their results. Too often faulty or conflicting advice as to the best use of land is given through lack of knowledge on the part of the adviser as to probable yield of forest products as compared with forage or other crops. The present educational campaign to advise private owners as to the best handling of their lands for benefits accruing to them direct should include such things as selection of wooded areas for various farm uses, such

[4] Final recommendations for a number of definite additions have already been presented by the field officers of the Forest Service. Some of these have been approved by the National Forest Reservation Commission and some have to date only been approved by the Forest Service and the Department of the Interior and are awaiting action by the National Forest Reservation Commission. These additions should be made. In addition to them there are many other additions, most of them involving minor quantities of land, which under similar policies should be added; final recommendations for these have not yet been prepared.

as cultivation, grazing wood lots, and the balanced proportion of each, besides the methods of handling or improving each class.

GENERAL SUMMARY

Relatively speaking, the tributary basins of the Missouri become progressively of greater and greater influence on the flood situation in the Mississippi, and consequently their critical areas become more and more intense a problem the lower they lie in the drainage. One major reason is that the nearer to the mouth of the Missouri the more direct influence is a stream's flow on the Mississippi water stages during the flood periods—i. e., the more the run-off becomes a part of the flood run-off of the Mississippi. The other reason groups all of the physical factors (both natural and as the result of culture) which affect quantity and rapidity of flood-contributing run-off, which are intensified progressively toward the mouth of the Missouri.

It may broadly be stated also that the upper drainages are concerned with erosion and silt carriage mainly, and the lower drainages provide the Missouri's contribution to the Mississippi floods.

By and large, the greatest needs in the Missouri Basin to ameliorate its effect on the Mississippi floods come from the conditions surrounding two groups of lands. The predominant detrimental influences are from the farming country in the lower southeast portion of the basin and from the Bad Lands of the northern portions. The first requires principally the educating of the private owners through the extension services concerned fundamentally in getting owners to make changes in their farming, including pasturage, practices which would primarily benefit them directly. The second is a problem of the Federal Government, to determine through investigation, and take whatever steps are found possible to bind the soil by means of establishing some kind of vegetation.

Of secondary importance are the removal of detrimental influences elsewhere in the whole basin, and the continuance of beneficial influences principally in the upper portion of the basin. On these forest lands certain practices should be followed in order to maintain their beneficial effect.

Forest management.—Present forest practices, wherever new growth is being brought about through careful cutting on national forest land, should be extended to all forested lands in the region. Cut-over areas should not be left in a condition which will permit further erosion. Protection strips of hardwoods should be maintained along stream banks, particularly in the agricultural and lower grazing belts, in order to maintain these from caving and bank erosion.

Forest protection.—Present methods of fire protection should be continued and intensified. A considerably greater amount of money should be expended in the protection of forest areas under section 2 of the Clarke-McNary Act than is now being spent.

Forest planting.—On denuded areas, and particularly on areas in the forest belt which are subject to erosion, a forest cover should be maintained, and where such trees are lacking this can only be brought about through forest planting. Federal and State agencies

should make available planting stock to private owners in greater quantity under section 4 of the Clarke-McNary Act. There is need for an extension of farm wood lots and shelter belts in the lower Mississippi involving some 5,000 to 6,000 square miles now being eroded by wind.

Research.—A special problem in the establishment of a suitable grass, forest, or other cover exists in the Bad Lands and part of this problem involves the question of proper-grazing practices. Research is necessary to determine the effectiveness of the different kinds of cover, the possibility and feasibility of tree or other planting, and the possibility of the use of engineering works to prevent further erosion. In the forested area research is also needed to work out the best methods of handling forest lands in order to keep them in a continuous cover and to determine the most practical and feasible methods to be used in planting as well as the most desirable class and character of planting stock.

PART V

FOREST CONDITIONS WITHIN THE ARKANSAS-WHITE RIVER BASIN

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CONTENTS

PART V

FOREST CONDITIONS WITHIN THE ARKANSAS-WHITE RIVER BASIN

SALIENT FEATURES

Outstanding features of the Arkansas-White River system which have an extremely important influence on floods in the lower Mississippi are as follows:

1. The area of the Arkansas River Basin as a whole is 16.5 per cent of that of the basin of the Mississippi River above the confluence of the two streams. The Arkansas River has contributed since 1911 an average of only 14.2 per cent to the important flood peak waters of the Mississippi River as they pass Arkansas City. That is, this tributary basin has contributed on an average a much smaller proportion of the flood waters than the remaining part of the Mississippi River Basin. But though this is true of the Arkansas River Basin as a whole it is not true of its eastern sector embracing the Ozarkian[1] and the flood plains provinces. The western portion of the Arkansas River Basin constitutes about 12.5 per cent of the basin of the Mississippi River and has contributed since 1911 less than 2 per cent of the flood waters. The Ozarkian province, however, which constitutes less than 4 per cent of the Mississippi River Basin, has contributed on an average since 1911 in excess of 12 per cent of the flood flow of the Mississippi River at Arkansas City. An analysis of individual flood periods shows that the Ozarkian province contributed during the flood of April 21, 1927, in excess of 38.3 per cent of the flow past Arkansas City. Of the peak flood of 60.5 feet approximately 23 feet may be considered as having been contributed by this province. It contributed essentially 50 per cent of the peak flow of May 1, 1927, and nearly 24 per cent of that of May 7, 1927. It is doubtful if any other limited area on the Mississippi Basin contributes so large a proportion of flood waters to a large number of exceptional floods. The Ozarkian province is a region of flood origin. (See Tables 7 and 8 in the Appendix.)

2. Only four to five days are required for flood waters originating in the center of the Ozarkian province to reach the Mississippi River and to augment its flow. There is consequently but little opportunity for the flood crest to flatten out before it reaches the Mississippi River (or during its course to that river). It requires 13 days for flood waters which originate in eastern Oklahoma and southeastern Kansas to reach the Mississippi River, while a flood originating upon the head streams of the Arkansas requires about

[1] See under heading "Topography" for definition of terms and regions.

30 days, during which period in its progress it is flattened out to an elongated swell.

3. Within the Ozarkian province the White and Arkansas Rivers occupy contiguous basins and during a general storm the emptying out of their flood waters is synchronized. For this reason floods in these streams are soon and definitely reflected in augmented flood flow of the Mississippi River. On the other hand, since the drainage from the north slope of the Ozark dome adjoining the White River Basin in Missouri is to the northward, flood waters from streams fed from this north slope do not pass a given point on the Mississippi River until many days after water from near-by points on the White River basin has passed it. It requires a rain of at least 20 days for these north-flowing flood waters to augment flood waters from the Arkansas-White River Basin.

4. The destructive floods of the Mississippi River and the lower portions of the Arkansas River come as a rule not later than early June following the periods of heavy precipitation of March (the month of heaviest rainfall) and April. In the Ozarkian province (fig. 1) the heavy rainstorms of the plains begin in April, continue throughout May, the month of heaviest fall, and decline during the summer months. The run-off of the plains storms usually follows that of the Ozarkian province instead of augmenting it, though there is a period of overlap during April.

5. The Arkansas-White River Basin is within itself an important flood unit in addition to being a heavy contributor to the flood waters of the Mississippi River. The section of the Arkansas River below Little Rock and the section of the White River below Clarendon suffer from the devastating effects of periodic floods. The levees in these sections while not so high as those on the adjoining portions of the Mississippi River are maintained at great expense, and a serious crevasse in a levee (fig. 1) is often accompanied by great loss, destruction of crops and livestock, injury to buildings, loss of use of land, and permanent impairment of land fertility.

6. The area of forest lands in the Arkansas-White River Basin has decreased from 59,000 square miles to about 34,000 square miles. Though the original forest covered 31 per cent of the area of the basin of these streams the present forest covers only about 18 per cent. The extensive cultivation of steep lands which are eroding and in particular the large area of marginal farming lands which were at one time under cultivation but which have been abandoned result in a further disarrangement of the natural equilibrium. The present area of improved tilled lands (other than grass) is 20,200 square miles, or about 11 per cent of the area of the basin, about equally divided between drilled and clean-tilled crops and largely concentrated, in the eastern half of the basin. The larger part of the farming land and the region where there has been the greatest decrease in the forest area lie within the region of heaviest rainfall, which is the region of flood origin. This loss in natural water-storage facilities must be replaced by storage of storm water through other agencies.

7. Amelioration of flood conditions, except in so far as they may be influenced by the silt burden, must be effected primarily within the eastern or Ozarkian province of these streams. The silt burden, however, is a major problem of the plains streams.

FIGURE 1.—Break in levee, flood of April–May, 1927, Arkansas River. Crevasse in levee on the Arkansas River north of Pine Bluff, Ark., showing (1) river bank on lower right; (2) strip between levee and river bank. This strip probably should be kept in timber as a protection against erosion of the levee; (3) levee and crevasse; (4) recently flooded alluvial lands covered with sediment lying within the levee and extending to the wooded uplands in the background. (Photo, Army Air Service)

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FIGURE 2.—Badly eroded lands along the "breaks," Arkansas River Basin. Characteristic surface of "breaks" along the Canadian River through the red Permian formation. Similar surface characterizes the Dry Cimarron and a number of other streams tributary to the Canadian. The trees are mesquite, which has within a century pushed its distribution many hundred miles to the northward. (Photo, United States Geological Survey)

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8. The larger part of the enormous silt burden of the Arkansas River is derived from the plains province chiefly from the "breaks" and from the hills of middle eastern Kansas. (Fig. 2.) The control of this erosion presents a serious problem. The silt burden which results from it perceptibly swells the flood waters of the Arkansas River in its lower reaches and those of the Mississippi as well to some extent. Its deposit as the current becomes less swift is the chief cause of the shifting of stream banks which is constantly in progress in the stretch of the river below Little Rock and it adds materially to the silt burden and the silt problem of the lower part of the Mississippi River.

9. The forest, as has been pointed out,[2] can not replace engineering means of flood control, but supplements these methods of control and in certain regions adds greatly to their effectiveness and permanence. In the Ozarkian province levees and storage of storm water in reservoirs may be the most effective means of obtaining assurance of relief from floods; and the effectiveness and permanency of reservoirs and other engineering works will best be assured by reducing erosion of soil to a minimum and by promoting better soil storage of storm waters. The reduction of erosion from rolling farm lands is to be assured by better methods of tillage, especially in eastern Oklahoma and the Ozark province where the cultivation of cotton and corn results in exposure of the soil to torrential rains (see pp. 220 to 222), by the employment of cover crops (see pp. 240–241), by the use of terraces and dikes and other means of promoting absorption and soil storage of precipitation. There should be a great expansion of farm woods on steep slopes in eastern Oklahoma and better protection of farm woods throughout this sector of the basin.

An extension of State and other public holdings for parks and forests, particularly in southern Missouri, where the area of such holdings is entirely inadequate, is urgent. There should be a minimum of 1,000,000 acres of State and other public holdings in the Ozarks of southern Missouri. An extension of the national-forest system in the Ozarks of Arkansas and the development of State holdings as supplemental to the national-forest system to include a total of 2,000,000 acres in public forests is desirable. This should be supplemented by extension of the cooperative work in the protection of forest lands against fire conducted under the act of March 1, 1911, and section 2 of the act of June 7, 1924, between the Federal Government and the State of Arkansas with the object of reducing the area of woodland which is burned over in the Ozark province, thus permitting the building up of a layer of humus to a maximum depth. (See pp. 239–240.) Such an increase in the thickness of the humus will not only lessen soil erosion within the forest and promote greater absorption of storm waters but will within itself supplement greatly the capacity of the soil to store precipitation water. If the layer of humus within the wooded portion of the Ozark province now extremely thin could be increased by a depth of 1 inch, supplementing the soil storage to that extent it might absorb and hold the equivalent of 5 feet of flood crest waters in the Mississippi River as it would pass Arkansas City, amounting to 158,000 second-feet for a period of 1 day and 15 hours.

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[2] Report of the Inland Water Ways Commission, p. 534, 1909.

10. While the headwater streams and those of the plains province contribute relatively little water to the Mississippi River floods, they are themselves subject to devastating floods of the cloud-burst type. Storage of storm water on these streams whether through artificial storage by reservoirs, or by permitting more thorough soil absorption, accompanied by a reduction in the erosion of soil, would have only a nominal influence upon the flood flow of the Mississippi River, however important such storage might be in the control of local floods.

11. The rapid silting up of reservoirs located upon the headwater streams in the foothills of the Rocky Mountains and in the plains province, due to the high silt burden carried by these streams during flood periods, is a serious menace to the storage capacity and to the prolonged utility of such reservoirs.

12. The control of erosion from the "breaks" and from other lands which are subject to excessive eroding is a most serious problem. Erosion from these lands will be lessened through better agricultural and range management,[3] through more careful control of grazing and the prevention of overgrazing, through the use of winter cover crops, by restricting the cultivation of lands which erode to grass or to crops which protect the surface in place of clean tilled crops, by means of crop rotation with a view to maintaining porous condition, and by the protection of existing woodland and the extension of woodland in the form of windbreaks and farm plantations throughout the plains and high plains region. (Under sec. 2 of the act of June 7, 1924.)

GENERAL DESCRIPTION OF THE BASIN

Location.—The Arkansas River Basin, including the basin of the White River, which flows into the Arkansas River at its mouth, occupies 188,342 square miles or 15 per cent of the total area of the Mississippi River Basin and is the greatest western affluent of the Missouri-Mississippi River system. Flowing to the south of east, it flows directly into the Mississippi 700 miles above its mouth. It has a length of 1,497 miles. Its watershed covers portions of seven States: Arkansas, Missouri, Oklahoma, Kansas, Colorado, New Mexico, and Texas. This basin is an elongated quadrilateral, the northwestern corner of which rests on the crests of the Continental Divide in central Colorado and the southwestern corner on the mountains of north central New Mexico. The northern line of the western portion of the basin lies in middle Kansas, just to the south of the thirty-ninth parallel of latitude; its south line through middle Oklahoma and the Panhandle of Texas is close to the thirty-fifth parallel. The eastern part of the basin, excluding the White River, occupies a wedge-shaped area extending through Arkansas from northwest to southeast, the broad apex to the west and including a small portion of southwestern Missouri and the adjacent part of Oklahoma.

The White River, occupying a fan-shaped basin of 27,678 square miles, is the largest lower tributary and joins the Arkansas from the

[3] Dallas (Texas) Morning News, Sept. 18, 1921.

north near the confluence of the Arkansas with the Mississippi. It drains the larger portion of the Ozark Plateau in northern Arkansas and southern Missouri. It is the most important tributary in point of sustained flow, and is likewise a large contributor of flood waters to the lower Mississippi River.

The upper portion of the Arkansas River is broken into four important branches. The main Arkansas drains the northern third of the basin and heads in the Rocky Mountains; the South Canadian drains the southern third of the basin, and likewise heads in the Rocky Mountains. These are typical eastern Rocky Mountain streams in respect to the character of the surface and stream flow. Between these streams lie the narrow basins of the Dry Cimarron to the north, and the North Canadian to the south of it. These streams do not head in the Rocky Mountains, but in the high plains to the eastward, and have the salient characteristics of plains streams in their surface and flowage. The important tributaries within and near the eastern wedge-shaped portion of the basin, the waters of which contribute in greater or less amounts to the flood periods of the lower river, are the Verdigris, the Neosho coming in from the north, and the Poteau and the Petit Jean from the south.

The areas of the basins of the Arkansas River and its tributaries, by States, are as follows:

TABLE 1.—*Area of the Arkansas River Basin (including White River)*

Tributaries	Arkansas	Colorado	Kansas	Missouri	New Mexico	Oklahoma	Texas	All States
	Square miles	*Square miles*	*Square miles*	*Square miles*	*Square miles*	*Square miles*	*Square miles*	*Square miles*
Arkansas-White (direct)	12, 289	26, 168	35, 530	2, 887	134	18, 359	--------	95, 367
Canadian	--------	--------	--------	--------	16, 046	18, 366	13, 140	47, 552
Cimarron	--------	2, 101	6, 157	--------	1, 009	8, 478	--------	17, 748
White River	17, 002	--------	--------	10, 658	--------	--------	--------	27, 674
Arkansas-White River Basin	29, 311	28, 269	41, 678	13, 543	17, 189	45, 203	13, 140	188, 352

Topography.—The Arkansas River Basin, including the White River, occupies four different physiographic provinces or regions. (Table No. 2.)

(1) The Mississippi River flood plain and coastal plains region discussed as flood-plain province; area, 2,580 square miles, 1.4 per cent of the Arkansas Basin.

(2) The Ozark and Ouachita Mountain regions, discussed as the Ozark province; area, 45,825 square miles, 24.3 per cent of basin.

(3) The prairie plains and high plains regions, discussed as the plains province; area, 105,755 square miles, 56.1 per cent of basin.

(4) The Rocky Mountain region or headwater province: area, 34,440 square miles, 18.2 per cent of basin.

The extreme eastern end of the basin of the main Arkansas River below Little Rock lies within the nearly level Mississippi River flood plain. It is drained by sluggish bayous and alluvial streams. This stretch of the river has a length of 173 miles with a fall of only 0.65 foot per mile. There are numerous oxbows marking locations of former channels. This division occupies 1,976 square miles, of which 1,400 square miles, or 1.5 per cent of the area of the basin, is alluvial

lands. It is this portion of the basin which is most subject to flooding. The basin of the White River occupies in addition 604 square miles of this province.

That portion of the basin that is in Arkansas above Little Rock and includes the adjacent portion of Oklahoma, southwestern Missouri, and the extreme southeastern tip of Kansas is within the Ozark and Ouachita Mountain regions. In Arkansas this portion of the river occupies a trough between the Ozark and Ouachita Mountains, which wall the basin to the north and south, respectively. From Wichita, Kans., within the eastern edge of the low plains, a distance of 659 miles to Little Rock, elevation 112 feet, the fall is about 1.5 feet to the mile, and the stream is not rapid. At the southern edge of the Ozark uplift the Boston Mountains, forming the rim of this portion of the basin, rise to more than 2,000 feet, or 1,600 feet above the valley floor, while to the south the Rich and Petit Jean Mountains, on the northern escarpment of the Ouachita Mountains, rise to elevations in excess of 2,600 feet, their crests being from 2,000 to 2,200 feet above the valley floor. The flood plain itself, from 6 to 12 miles in width through this stretch, is bordered on each side by a rolling terrain. The width of the valley between the bases of the abutting sharp-rising hills and mountains varies from 10 to 30 miles. This province extends up the main river to Arkansas City, Kans. The Arkansas River, above its junction with the Canadian River, "winds through a rather deep and narrow valley among the Flint Hills of the Ozarkian uplift, where it is characterized by sweeping curves. The surface of the whole region lying near the river is dissected into a series of hills and hollows by the small tributary streams. The distance traversed by the river through the limestone hills is about 83 miles direct, but as traversed by the stream it is nearly twice as great. The valley between the bluffs, which are from 150 to 300 feet high, is from 1 to 5 miles wide."

The third province, consisting of the prairies, plains, and high plains, occupies a broad stretch through middle and western Oklahoma, embraces essentially all of southern Kansas, the Panhandle of Texas, and the adjacent high-plains parts of Colorado and New Mexico. It lies within the prairie region in the extreme east and the plains and high-plains region to the west and southwest. The rise in the general levels is from an altitude of less than 800 feet at the east to 4,600 feet at Pueblo at the foot of the Rocky Mountains, a range of 3,800 feet. This portion of the basin consists of broad plains, especially to the east and northward. It is dissected and rough near the southern streams, the Canadian and the Cimarron, the channels of which are from 150 to 300 feet below the general surface level, and the bordering hills known as the "breaks" are much cut up. (Fig. 2.) This character of dissection continues on the basin to the northwest to the head of the Ninnescale and Medicine Rivers, tributaries of the Cimarron from the north; and extends to the north to Barber, Pratt, Comanche, and Clark Counties, Kans., along the southern border of the State and well within its western portion.

Also in the high-plains region of Texas, drained by the Canadian River and the Cimarron, "there is, away from the level of the plateau, much of broad dissection, in places low mountains and long ridges

and sharp escarpments, while the streams lie usually in deep gorges or canyons with little or no alluvial lands except along the largest. The surface of the plains farther westward along these streams, the Canadian and Cimarron, is not so dissected back from the river canyons. It rises with low escarpments from terrace to terrace, but always with a prevailing higher trend to the northwestward. But in certain sections to the west, occasional low ridges, buttes, and knobs, rise above the general level, while skirting the rivers for many miles there are belts of rolling sand hills, though of comparatively limited area." The prevailing level surface of the prairies and plains also passes into a very hilly terrain in middle Kansas and on the headwaters of the Neosho and Cottonwood Rivers.

The Arkansas River proper, however, flows through the plains in a broad, shallow valley from the point where it debouches from the mountains of Colorado, after leaving the canyon of the Colorado at Canon City, until it reaches the Flint Hills at Arkansas City, Kans., near the Oklahoma line. From Canon City, Colo., to Wichita, Kans., a distance of 543 miles, the fall of the Arkansas River is 7.5 feet per mile.

In places the flood plains of the North Canadian and Cimarron Rivers, which are hardly anywhere as much as a mile wide and which are covered by nearly every flood, consist of sandy or gravel river wash. That of the South Canadian, of the same type, is from one-half to 2 miles wide. But the main Arkansas River and most of its tributaries through Kansas are skirted by a broad belt of alluvial lands, chiefly a flood plain from one-half to 5 miles in width. This flood plain occupies about 2 per cent of the basin. On account of the configuration of the upland surface, the limited rainfall, the treeless character of the upland, and the prevailing loose soils, which, as a rule, absorb most of the rains, the alluvial lands are not of high importance in connection with flood control.

The fourth or western province, the headwaters, includes the eastern slope of the Rocky Mountains, south to the foothills and mesas and the inclusive valleys. This portion of the basin rises from a base level of about 5,000 feet along the plains at the edge of the foothills and rapidly ascends in steep slopes to high elevations where, "at an altitude in excess of 10,000 feet, the river (Arkansas) has its source in a pocket of lofty peaks in middle Colorado. There are broad valleys between the foothills, but these as the streams ramify into the mountains become narrow. Through this course, the river is a mountain torrent." At Canon City, the Arkansas passes out of the Rockies through the Grand Canyon of the Arkansas, largely as a clear stream, and with steadily lessening gradient flows into the plains of Colorado and Kansas.

The headwaters of the Arkansas in Colorado and including Purgatory River occupy a triangular basin about 260 miles long, Purgatory River forming the south side of the triangle and the head of the Arkansas the north arm. The gradient of the river is 40 feet per mile for the lowest stretch, but the head of the Arkansas River, as well as the head of Purgatory River and of the shorter side streams, ascends more than 60 feet per mile. The area of this headwater province, essentially the area of the river above the mouth of the Purgatory River, is about 21,000 square miles: 3,900 square

miles are classed as mountains, 4,500 as plateaus, 12,600 as plains. The mountains range in elevation from 8,000 to 14,000 feet, some of the peaks bearing snow fields.

The headwaters of the South Canadian, in New Mexico, embrace 12,500 square miles, omitting Big Blue Creek. Of this area 4,600 square miles is classified as plateau, 4,000 as plains, 3,900 as mountains, ranging in elevation from 8,000 to 12,000 feet, some of the peaks being covered with perpetual snow and having little vegetation.

The Dry Cimarron and the North Canadian head below the Rocky Mountains in the lower edge of the foothills and mesas. They are typical plains streams.

TABLE 2.—*Character of surface of Arkansas River Basin*

Stream and province	Total area	Level or gently rolling	Per cent	Very hilly and broken	Per cent	Mountainous	Per cent
White:							
Ozark province and flood plain	*Square miles* 27,678	*Square miles* 8,856	32	*Square miles* 11,348	41	*Square miles* 7,474	27
Arkansas:							
Flood plain	1,976	1,876	95	100	5		
Ozark province	18,759	2,064	11	7,127	38	9,568	51
Plain province	53,749	42,461	79	10,211	19	1,077	2
Heads province	20,883	12,566	60	4,488	22	3,829	18
Total for Arkansas direct	95,367	58,967	62	21,926	23	14,474	15
Canadian:							
Plains province	35,084	25,964	74	8,419	24	701	2
Headwaters province	12,468	3,990	32	4,588	37	3,890	31
Total Canadian	47,552	29,954	63	13,007	27	4,591	10
Cimarron: Plains province	17,745	12,778	72	4,967	28		
Entire basin	188,342	110,555	59	51,248	27	26,539	14

Of the total area of the basin 16,951 square miles, or 9 per cent, is between 100 and 500 feet in elevation; 36,538 square miles, or 19.4 per cent, is between 500 and 1,000 feet; 47,839 square miles, or 25.4 per cent, is between 1,000 and 2,000 feet; 56,314 square miles, or 29.9 per cent, is between 2,000 and 5,000 feet; 24,861 square miles, or 13.2 per cent, is between 5,000 and 8,000 feet; 5,839 square miles, or 3.1 per cent, is over 8,000 feet.

(A) *Geology and origin of soils.*—The geological formations which underlie the basins of the Arkansas River and the soils derived therefrom vary as widely as does the surface. The extreme eastern end of the basin, lying within the comparatively recent formations (the Quarternary and Pleistocene) constitute the alluvials of the Mississippi bottoms and the islands of loess and the better-drained areas of unconsolidated loams, clays, sands, and gravel within the flood plain. It is all land built up recently through contributions from the various soils on the upper portion of the basin on which erosion is now actively taking place. The loess formation is essentially limited to a few small areas, the largest being Crowley's ridge, the western slope of which is within the basin of the Arkansas River.

A wide range of geological formations is represented in the Ozark and Ouachita physiographic regions, which occupy the upland part of the basin in Arkansas, in southwestern Missouri, and in the adjacent portion of Oklahoma. The northern part of this area is formed largely of limestones and dolomites of the Ordovician period.

FIGURE 3.—Sand hills characteristic of high plains streams, Arkansas River Basin. Sand hills of this type border the north and south Canadian and the Dry Cimarron Rivers and their tributaries chiefly on their north banks throughout middle and western Oklahoma, across the panhandle of Texas and into New Mexico. Similar sand hills border the Arkansas River, mainly on the south side, throughout southwestern Kansas and into southeastern Colorado. These sand hills are storage reservoirs for the waters of heavy rains which mark this region. They erode only slightly or not at all. Where they rest upon less permeable strata numerous springs occur. Many of these sand hills, even in the desert country, are at least partially wooded with shin oak as well as with other small trees and shrubs, the sands being the only upland soils in this region which carry sufficient year-long water to support tree growth. (Photo, United States Geological Survey)

Figure 4.—Typical stream bank erosion, plains province, Arkansas River Basin. Erosion of Bruff Creek, Huerfano County, Colo. Height of bank is 50 feet

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FIGURE 5.—Chert mantle protecting soil. Ozark province, Arkansas River Basin. A mantle of gravel and small stones, chiefly chert, covers thousands of acres in the Ozark region particularly on the basin of the White River and throughout the Boone chert area and the flint hill region of northeastern Oklahoma, extending into the adjacent parts of Missouri and Kansas. Such a mantle of stone does much to lessen erosion and to promote absorption of precipitation by soil and subsoil. It has no water-carrying capacity itself like that of humus beneath a forest. Many of the soils protected by the chert mantle are silty and without this protection erosion would be greatly accelerated. (Photograph taken in Arkansas, land in cultivation in corn in 1925)

The northwestern portion includes the Boone chert area of the lower Carboniferous or Mississippian age. The rocks in this portion of the basin are largely of limestone with shales and sandstone to the west and north horizontally stratified. The Boston Mountains immediately to the north of, and the Ouachitas immediately to the south of, the Arkansas River are occupied mainly by rocks of Pennsylvanian or upper Carboniferous age, consisting of some limestone and heavy deposits of sandstone and shale, the strata of which are interrupted and faulted, there being monoclines from the Boston Mountains to the Arkansas River valley.

To the west of the Ozark and Ouachita Mountain provinces the low plains, largely of lower Carboniferous (Mississippian) age, embrace southeastern Kansas and northeastern Oklahoma, the strata largely bedded horizontally. Pennsylvanian series of the Carboniferous age lie to the northwestward, extending through eastern Kansas, the rocks prevailingly shale and sandstone, though limestone occurs in places and there is a broad belt of gypsum in Oklahoma. In the panhandle country and extending northward through Oklahoma into southern Kansas, the Permian red sandstone, sandy shales, and clays constituting the red beds of the lower Carboniferous, extend over many thousands of square miles, giving the distinctive red color to the walls of the canyons, the sides of the gorges, to the local soils (the cotton soils of the panhandle country), imparting this color to the waters of the rivers and even to the alluvial soils built up from these formations far downstream. (Fig. 2.) Even where the red beds are overlaid by the more recent formations they still contribute, through corrasion of banks and by erosion of slopes, a large part of the solid burden to the Canadian River and to the Dry Cimarron, on those portions of the basins where these beds form the bottom or sides of the gorges occupied by these rivers and their tributaries.

North of the Arkansas River in middle Kansas and in southeastern Colorado and northeastern New Mexico shales of the Cretaceous age occur, from which are produced an extensive series of soils chiefly silty and loamy in character.

The unconsolidated plain marls of the Tertiary sedimentary formations cover considerable areas in southwestern Kansas. From Taloga, Okla., throughout the panhandle of Texas, to the foot of the Rocky Mountains just east of Mora, N. Mex., Tertiary beds exist, consisting of sands, clays, and conglomerates, sometimes containing calcite concretions and with harder bands intermixed. Many of the sand deposits in particular border the larger streams, occupying considerable areas of the high plains. (Fig. 3.) Most of these deposits are unconsolidated; some are alluvial, others are supposed to be lacustrine; and others are of aeolean origin. They extend nearly to the upper edge of the plains of northeastern New Mexico and southeastern Colorado where they commingle with the silts of the upper Cretaceous series. Below them lies the massive sandstone of the Dakota formation, which extends to the lavas forming the mesas between the Cimarron and the Arkansas rivers and to the foot of the Rocky Mountains.

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The backbone of the Rocky Mountains is formed of igneous rocks, granites, gneiss, porphyries, and gabbro.

To the north of the Arkansas River in western Kansas glacial drift occurs, but it occupies only a relatively small portion of the basin.

The soils are of three distinct types:

1. Sands and similar soils having a high storage capacity for rainfall and eroding only slightly. These soils as a rule furnish abundant springs when they rest upon impermeable or less permeable strata. (Fig. 3.)

2. Silts, very fine sands, and fine sandy loams, which are deficient in cohesion, eroding rapidly under concentrated precipitation and contributing the largest element to the turbidity of the river. (Fig. 4.)

3. Clays and related soils with much cohesion, eroding but not so readily or destructively as the silts.

Many of the soils are very stony. This is particularly so over the Ozark region throughout the Boone chert area and portions of the Ouachita Mountains. The stone is often sufficiently abundant on the surface of the soil greatly to reduce erosion, especially where it forms a mantle covering the entire surface. (Fig. 5.) There are extensive areas of this kind in the Ozarks and Ouachitas and on the slopes of canyons and gorges. While such a mantle of stone does much to lessen erosion and to promote absorption of precipitation by soil and subsoil, it has no water-carrying capacity itself, such as does humus beneath a forest.

Table 3 shows the areas of the different classes of soils on the basins of different streams.

In general it may be said that over the Ozark dome silty and loamy soils prevail, but that a considerable portion of these is protected by a mantle of chert. In the Ouachitas there are large areas of loams and clay soils. The areas of sands in this eastern portion of the basin outside of the alluvials are limited.

In the plains and prairies the prevailing upland soils are silts and related soils, subject, when on a slope and when denuded, to excessive erosion after heavy precipitation. There are also extensive areas of sands bordering the larger streams especially on the north sides of the Canadian River and the Cimarron River, as well as along the main Arkansas in western Kansas, particularly in the vicinity of Garden City. There are considerable areas of clayey soils, but these are largely on level or rolling terrain, as in the panhandle of Texas and in other parts of the plain.

The soils of the Rocky Mountain province embracing the Rocky Mountains and their foothills are largely shallow and stony, chiefly loams and clay, though silty in places, especially on the mesas. The silts are often tenacious on account of a clay content and, moreover, they frequently are so stony on the surface as to be largely protected from ordinary precipitation. There are beds of sand along the Arkansas and the Canadian Rivers through the adjacent plains.

The soils of the Ozarkian province except the alluvials and valley lands are largely shallow or of medium depth. Over considerable areas they are stony or are covered with a mantle of chert and gravel. This cover is particularly extensive on the lower part of

the basin of the Neosho River and on the Illinois Bayou, but occurs also in many other sections. In many places the shales or other underlying rocks nearly come to the surface. As a rule, however, the subsoil drainage on account of the fissured character of the rock, both limestones as well as shales, is good; and, in spite of the relatively shallow soils, there is prevailingly rapid absorption of heavy rain, which is promoted by the blanket of chert gravel wherever this occurs. On account of this condition erosion of soil is not so active throughout this region as otherwise would be the case considering the frequently concentrated character of the precipitation, the steepness of the slopes, and the shallowness of the soils. The soils themselves are clays, loams, silt loams, and silts, and are agricultural in character where the surface is not too steep and where the soils are not too shallow or stony, or where the chert drift is not too thick to preclude cultivation, as is often the case. The rainfall throughout this province is so heavy that the soils are leached of a large part of the more soluble mineral material, while the rainfall and temperature both promote the rapid oxidation and destruction of humus whether it is incorporated in the soil or is the superficial accumulation of forest leaf mold.

In the plains and prairie province, the upland soils vary widely in composition and character, but are alike in that on account of the limited rainfall, particularly during the winter months, they have not been leached of their soluble mineral elements, and therefore, as a rule, contain a high proportion of lime carbonates. The presence of the lime promotes the retention of humus in these soils and is one of the most important factors in determining their high fertility, even where they have been derived by the decay in situ of a country rock, such as sandstone, naturally low in the elements of plant food. This condition is more pronounced as the precipitation becomes less, until it reaches a point where there is too little precipitation, or it is too irregularly distributed for the production of agricultural crops even under dry farming systems.

Prevailingly over the prairie or eastern portion of this province the upland soils are derived from the underlying rocks or have been but little transported as a result of normal local shifting. The soils through the western portion of this province, especially to the northward in southern Kansas, are not derived from the country rock, but are of aeolian or fluvial origin, loose and unconsolidated, the surface being level or in slightly rolling drifts due to the wind action. The Arkansas River itself for several hundred miles on its south bank is flanked by stretches of loose sand, often fixed but sometimes in transient dunes, entirely unconsolidated, and these sands extend into Colorado. To the southward, particularly in the panhandle region, there are fewer large areas of unconsolidated soils. The prevailing phases are silts, loams, and clays which are as a rule beaten into adobe by the infrequent, but often torrential, rains. The silts, loams, and clays of the plains follow the rivers to the foothills of the mountains.

The soils of the alluvials and flood plains are sands, silts, and clays. Those of the eastern province have material influence upon the flowage of the river, due to the constant corrasion of banks throughout this stretch of the river. The flood plains become very narrow up

the Canadian and Cimarron Rivers. On the South Canadian the flood plains consist largely of sand and gravel river wash, but near the head of that stream the valley widens out and contains in places considerable silty alluvial deposit not only along the main head of the river but along the Mora River and the Cimarron (of New Mexico) as well. Above Arkansas City the Arkansas River flows in a broad valley with wide alluvials, mostly soils of good quality, sands, loams, and silts, a broad belt often several miles in width and extending nearly to the mouth of the canyon through which it courses in its descent through the foothill region. The alluvial lands at the head of the river are more sandy and are less extensive.

TABLE No. 3.—*Soils of the Arkansas River Basin*

	Porous sands and sandy loams	Per cent	Silts and other easily eroded soils	Per cent	Upland clays and soils with cohesion	Per cent	Very stony land not subject to severe erosion	Per cent	Alluvials	Per cent	Total area of basin
	Sq. mi.		*Sq. mi.*		*Sq. mi.*		*Sq. mi.*				
White	2,085	7	9,114	33	2,400	9	13,318	48	761	3	27,678
Arkansas flood plain province	--------	------	581	29	--------	------	--------	------	1,395	71	1,976
Ozarkian	376	2	6,186	33	2,257	12	8,435	45	1,505	8	18,759
Plains	5,898	11	34,945	65	8,054	15	3,235	6	1,617	3	53,749
Headwaters	1,200	6	10,945	52	--------	------	8,318	40	420	2	20,883
Total Arkansas direct	7,474	8	52,657	55	10,311	11	19,988	21	4,937	5	95,367
Canadian plains	4,010	11.4	21,721	61	3,625	10.3	5,271	15	457	1.3	35,084
Headwaters	1,875	15	6,730	54	1,250	10	2,488	20	125	1	12,468
Total Canadian	5,885	12.3	28,451	60	4,875	10.2	7,759	16.3	582	1.2	47,552
Cimarron plains	900	5	12,295	73	2,510	15	834	.05	200	2	16,739
Plateau	--------	------	1,006	100	--------	------	--------	------	--------	------	1,006
Total Cimarron	900	5	13,301	75	2,510	14	834	4	200	2	17,745
Total for basin	16,344	8.7	103,523	55	20,096	11	41,899	22	6,480	3.3	188,342

Climate.—The basin of the Arkansas River, with its wide stretch from east to west and with a variation in altitude of from a few hundred feet above sea level in its eastern portion to more than 10,000 feet in its western, presents great extremes of climate especially in amount of precipitation, in character of the precipitation, and in evaporation.

The precipitation is extremely heavy in the eastern part of the basin on the White River drainage, where at many points it is in excess of 50 inches for a year, and with only a few inches of snowfall. It becomes gradually less toward the west, reaching a minimum of about 12 inches over limited areas of northeastern New Mexico and adjacent Colorado, and again rising with the ascent of the Rocky Mountains.

Over a great part of White River Basin, and the Ozark province and the flood plain province of the Arkansas River, the average annual precipitation is about 45 inches, the amount of unmelted snowfall being about 7 inches.

The heaviest rainfall in this region, amounting to nearly 55 inches a year, is probably in Lawrence County, Ark., at an altitude of be-

tween 200 and 300 feet, although other points in the extreme eastern and southern parts of the basin show yearly averages of nearly equal amount. While this heavy annual precipitation on the lower part of the basin is fairly evenly distributed throughout the year decidedly the greater part of it falls during the winter and summer months when the rainstorms from the southwest are often of a most decidedly concentrated character, particularly in the eastern, southern, and middle parts of the basin. There is a short period of low rainfall in February and a longer period in the late autumn, culminating in October. (Fig. 6.) The concentrated character of the precipitation on the lower part of the basin, even during the months of low rainfall, is indicated by the following cases:

At Bee Branch, in Van Buren County Ark., in the middle part of the basin, 8.5 inches is recorded as having fallen in 24 hours in the month of October. At Calico Rock, in Izard County, Ark., within the same region, 8 inches has fallen during the month of August.

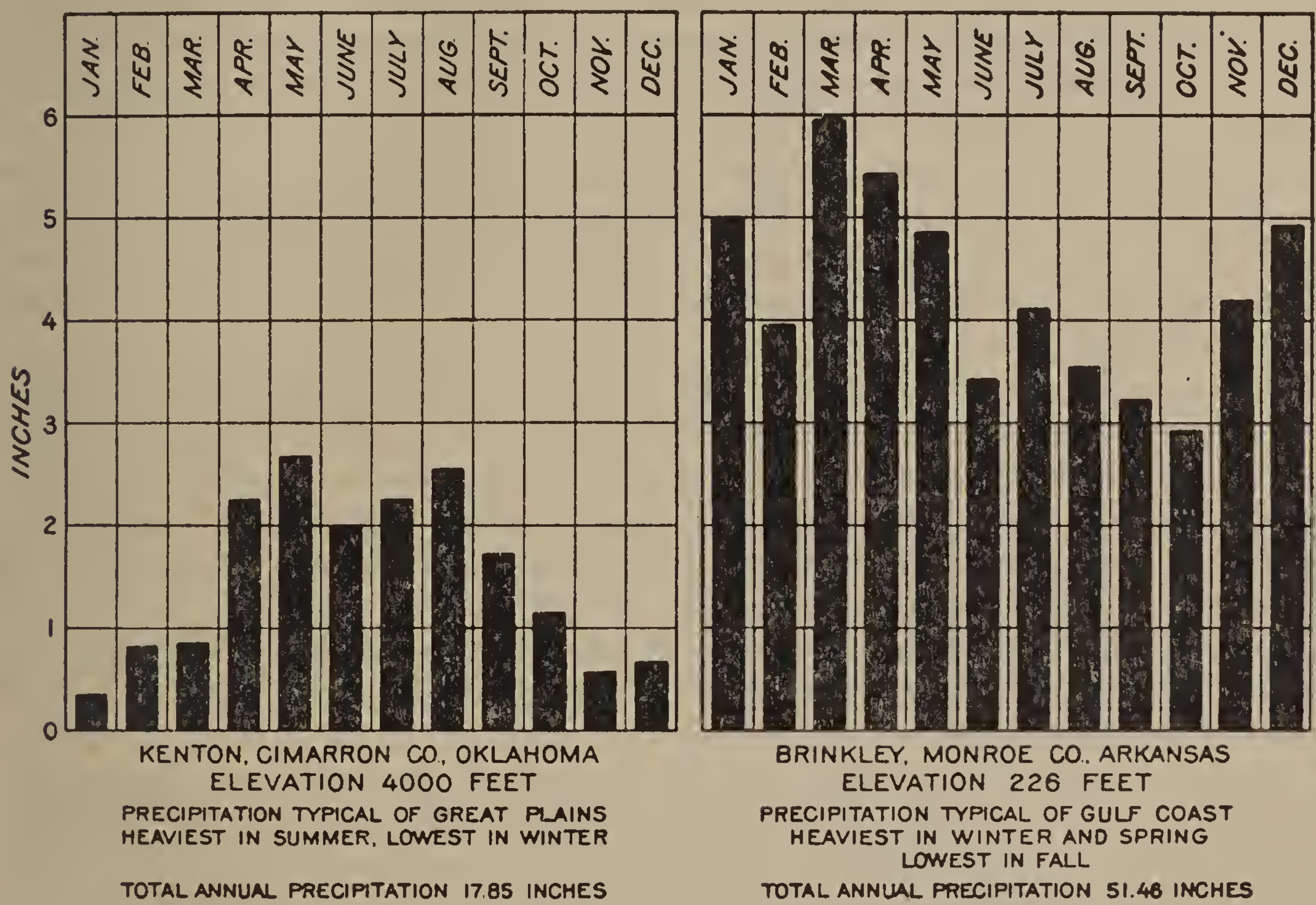

FIGURE 6.—Types of monthly distribution of precipitation

At Dodd City, in Marion County, Ark., in the same region, there is a record of 7.37 inches during the month of August. At Marianna, on the southeastern edge of the basin, 7.45 inches has fallen in October; at Dutton, Madison County, 7.19 inches has fallen in June. A precipitation of between 5 and 6 inches during a 24-hour period during the summer months is not uncommon at many points, even in the western and northern parts of the watershed, and a precipitation of from 4 to 5 inches frequently takes place on the eastern sector during the winter months within 24 hours. In addition to the rainstorms, chiefly from the southwest, about 40 thunderstorms, usually accompanied by concentrated precipitation, annually occur over the middle and eastern parts of the basin, most of them during the summer months.

The precipitation of the plains region varies from about 35 inches, of which 8 inches or less is unmelted snow, in the eastern portion to

about 29 inches in the panhandle of Texas and other parts of the high plains in Colorado, New Mexico, and Kansas, of which about 18 inches is unmelted snow. In the Rocky Mountains the precipitation rapidly rises with altitude, amounting to from 25 to 30 inches at higher altitudes, largely in the form of snow which melts chiefly in the late spring and early summer months.

There is difference in the character of precipitation. That along the basin of the St. Francis River and other points in the extreme east is decidedly of the Gulf type, heavy, and not very low during any month of the year. (Fig. 6.) The result of this is that there may be floods in the St. Francis River and associated streams in the winter as well as in the spring and summer. The precipitation of the Ozark and Ouachita regions is heaviest during the winter and late spring, and for this reason floods originating on streams in this region are chiefly during these periods. But floods occasionally occur in the fall, as shown by the flood of October 2–20, 1926. The precipitation in the plains region is heaviest during midsummer, often more than two-fifths of the entire annual amount falling during the four months, May to August, and is relatively small during winter. (Fig. 6.) There is also marked irregularity in the precipitation in this region, there being long periods of low rainfall followed by heavy torrential downpours. As a result of this the floods in this region are largely limited to the late spring and summer months, and local floods often take place very quickly on account of the concentrated character of the rainfall.

The rainfall of the high plains, especially during the summer months, is even of a more irregular and concentrated character than that of the eastern portion of the plains province. At Two Buttes, Baca County, Colo., with an average annual precipitation of less than 15.5 inches, 8.56 inches, or more than half of the normal annual amount, has fallen within a single month. At Valos 6.71 inches has fallen in April, with an average annual precipitation of only 13.92 inches. For some years the total precipitation at this point has been as low as 5.38 inches.

Along the foothills and lower slopes of the Rocky Mountains there is in general this same type of plains rainfall, but the concentrated character of the midsummer precipitation is even more marked, often being in the form of what are called cloudbursts, local showers of great violence and extreme suddenness. The precipitation at the upper altitudes in the mountains is largely during the winter. The melting of the accumulated winter snow in late spring and summer causes rise in the streams but no floods, the run-off merely serving to reinforce the low-water stages of the river at this period.

Evaporation and run-off.—The actual amount of precipitation does not represent, nor is it a true index of, the amount of water which must be taken care of in planning for flood control. What must be taken care of is the proportion of rainfall which runs off, and this proportion varies in different regions and with the season.

The evaporation is relatively low in the extreme eastern portion of the basin on account of the high humidity and the generally low wind movement. On the plains, especially the high plains, the evaporation factor is high, especially in summer, high temperatures often

being accompanied by hot desiccating winds, the open-surface evaporation being considerably in excess of the rainfall. It is more than 45 inches in the plains region of Oklahoma and Kansas, and more than 50 inches in the low part of the Texas panhandle and on the plains of northeastern New Mexico. There is likewise considerable winter evaporation, mostly in the form of shrinkage of the snow after falling. The snowfall varies from 8 inches of unmelted snow in the extreme eastern part of the basin to about 20 inches in the high plains, and in excess of 40 inches at high altitudes in the Rocky Mountains. Only upon the extreme headwater streams does the snow melt result in floods or contribute to floods, and these floods are local, their crests being distributed soon after entering the plains.

Since the open-surface evaporation is highest in the plains region only a small part of the precipitation in the region as a rule finds its way into the streams. In the high plains province, embracing eastern Colorado, western Kansas, western Oklahoma, and the panhandle of Texas, less than 3 inches of the total average rainfall, which is about 20 inches, actually finds its way into the streams and runs off. In the low plains region covering eastern Kansas, eastern Oklahoma, and the extreme northwestern portion of Arkansas, and having a precipitation which varies from 22 inches along the western edge of the region to about 40 inches along the eastern edge, from 3 to 10 inches of the precipitation, on the average, runs off each year; while through the Ozark province, having a precipitation varying from 40 inches in the northwest to 55 inches in the southeast, the average run-off of the rainfall varies from 10 inches in the west to about 20 inches in the eastern edge of the province. That is, in this province about one-third of the rainfall actually enters the streams. The other portion is returned to the air by evaporation of soil moisture or by transpiration of forest and other vegetation in the exercise of their physiological functions. While this is true, the largest floods take place at those periods when evaporation and transpiration by plants is low; that is, during the spring and early summer while the soils are yet saturated by winter rains, following the period of lowest moisture evaporation.

Historical development.—The extreme eastern part of the basin of the Arkansas River was settled by the French explorers; but few of these settlements resulted in permanent agricultural development, being largely limited to trading with Indians and hunting fur. The first extensive settlements in the basin began in the 1830's and settlement progressed steadily westward, followed the main drainage lines and radiating therefrom. By 1860 the greater part of the basin of the White River and that of the Arkansas River as far as Fort Smith had been opened up. Settlements had also been made by that time on certain parts of the Arkansas River in eastern Kansas. The Arkansas River Basin of Kansas was largely opened up during the last quarter of the preceding century. That portion of the basin in Oklahoma, however, was little settled until the opening of Indian lands for settlement in 1899, followed by the creation of the Territory of Oklahoma, and there was a further inrush of settlers in 1902 and 1904, when other Indian lands were thrown open to settlement.

Settlement in the high plains country was first for the purpose of grazing cattle. The range has now been largely broken up into ranches and farms, although extensive areas within the region of low rainfall in eastern Colorado and New Mexico and large sections of rough land in middle and western Oklahoma are still handled for grazing purposes as range, though largely under fence. The total area of public lands in these States July 1, 1926, was as follows: Colorado, 394,844 acres; New Mexico, 283,045 acres; Oklahoma, 26,081 acres; and Arkansas, outside the national forests, 199,103 acres, a total of 903,073. No public lands remain in Kansas or Missouri. There was no public domain in Texas. The grazing of cattle in the prairie and plains section first gave way to the cultivation of wheat. Wheat gave way in part to Indian corn and kafir corn. Still more recently, in the southern part of the panhandle and over a considerable part of Oklahoma, cotton is being extensively cultivated, while in many sections a varied system of farming has been adopted. Throughout the entire basin, however, drilled crops, such as wheat, are the prevailing crops, with clean tilled crops, such as Indian corn, kafir corn, cotton, and soy beans secondary. There are considerable areas in alfalfa and hay, but such areas on the whole are not so extensive as farther north. Large areas of rough land, the mountains within the plains, and the "breaks" still remain in use for grazing and range purposes exclusively.

Settlement has been followed by changes (1) in the forest condition, (2) in the soil cover on the plains, (3) in the extent of erosion.

At the time of settlement large areas in the Ozark plateau region, especially on the White River drainage, were open prairie lands or dotted with scattered trees and bushes, the ground being clothed in sod chiefly of bluestem grass mixed with little bluestem. The "barrens" were mostly open, as were the "knobby" sections. As a result of settlement, such of the prairie openings within the Ozark region as have not been placed in cultivation are now occupied by woods, while both the barrens and knobs are now almost solidly in forests, although the trees are often small. On the whole it seems probable that the area of woodland, at least on the upper portion of the White River and on the Ozark drainage of the Arkansas River, it is at present no smaller than at the date of settlement. As the woods have spread, the bluestem has disappeared and is no longer regarded as a range or stock grass.

There has, however, been a decided reduction in the forest area of the lands immediately bordering the Arkansas River in Arkansas from the mouth of the river to Fort Smith, especially on the alluvials.

On the basin of the White River, as in the Ozark province of the main Arkansas, there has not been material decrease in the area in forest cover, because of the extensive area of prairies and openings in the forest which existed at the time of settlement, but a large area of rolling and hilly land has been placed in cultivation, and this has been followed by a great increase in the silt burden of the river, for the natural open lands occupied level areas.

Although the forest area of the Ozark province may have extended, it is doubtful if its extension has resulted in any general betterment in the protection of the surface of the soil in the case of the lands

upon which trees have replaced prairie grasses, because the prairie grasses formed a heavy sod, giving excellent protection. On the other hand, so much of the woodland which has replaced the prairies is now repeatedly burned that the humus conditions are poor and there is inadequate soil protection—less than with the heavily matted grasses. This applies to the entire Ozark province. There has been a slight reduction in the wooded area of Oklahoma, but most of the woods are either on hills or located upon broken lands or upon bottoms subject to flooding, the farming lands being located chiefly on the more level and gently rolling lands. The low plains and prairies of eastern Oklahoma lying within the woodland section and beyond the forested region were initially clothed in a good sod of short grasses, mostly buffalo and gramma. In the middle and eastern portions of Kansas and Oklahoma large areas have been cleared and put in cultivation. The result of this is far more extensive erosion from much of this land than there was before it was placed in cultivation. There has also been some change in the conditions of the woodland, due to excessive grazing. The more palatable browse and herbaceous plants have to a large extent been replaced by less palatable plants, particularly by prairie ragweed which has spread enormously, but, since ragweed is an annual, it does not give the protection to the soil during the winter and early spring which was afforded by the indigenous perennial grasses. There has also been, especially in the enclosed pastures, a great increase in the amount of other unpalatable annuals such as the narrow-leaf plantain and sneezeweed (*Helenium*).

This same condition extends to the high plains except that on the high plains a far smaller proportion of the land is tilled and a larger proportion is still in range. This particularly applies to the rougher and broken lands which form the breaks along the Canadian and Cimarron Rivers and their tributaries throughout the middle portion of the high plains sections. Range deterioration has taken place rapidly in this section, the blueweed in particular in many localities replacing the palatable and nutritious perennial grasses and affording at the same time far less protection to the soil from the torrential rains to which this region is subjected. The buffalo grass is one of the best soil-protective grasses as well as one of the most nutritious. But in spite of its hardiness and its ability to withstand rough treatment its sod in many places has been severely injured by overgrazing; other grasses less hardy, particularly the bunch grass, have suffered far more. As a result of range deterioration in this region, arroyos and gullies making into the "breaks" have been greatly increased in number and are rapidly extending their heads back and destructively eating into the level surface of the plains.

The headwater province was timbered on the mountain slopes and to some extent on the foothills, although the foothills and adjacent mesas were as a rule covered only in open woodland of cedar and pinon. Notwithstanding the fact that considerable lumbering has taken place in this region, as the result of settlement, there has been on the whole less detrimental results than in the middle portion of the basin.

TABLE 4.—*Forest lands: Arkansas River Basin and main tributaries*

Basin	Area of basin	Area of forest land	Per cent in forest	Area of woodland	Per cent in woodland	Per cent of area in forest and woodland	Per cent nonforest
	Square miles	*Square miles*		*Square miles*			
White River	27,678	18,700	68			68	32
Arkansas proper	95,367	14,900	15.5	2,780	2.9	18.4	81.9
Canadian	47,552	633	1.3	5,880	12.3	13.6	86.4
Cimarron	17,745			251	1.3	1.3	98.7
Total	188,342	34,233	18	8,911	4.7	22.7	77.3

The forest lands are largely within the Ozark and headwater provinces.

In the Ozark province by far the larger portion of the woods is on farms. There are large holdings, however, in particular on Current River and other streams on the White River drainage held by lumber companies, and a number of large areas held by mining companies. There are 2,926 square miles of national forests in the Ozark province, in part on the White and on the main Arkansas, while the State of Missouri has in State forests and State parks about 41 square miles in five units on the White River. In the headwater province there are 1,930 square miles of national forest on the Arkansas River proper and 55 square miles on the Canadian River in New Mexico.

CONDITION OF NONFORESTED LANDS

There are two large classes of nonforested lands on the basin of the Arkansas River. One class contains those lands which are in cultivation or held as parts of farms or ranches. The other class consists essentially of the large areas of public domain which are not included in farms but which have been used as public grazing lands. The area of the improved tilled lands (other than grass) on the basin is about 20,200 square miles, of which 9,242 square miles are in tilled crops and 10,986 square miles in drilled crops. The public domain, amounting to 1,410 square miles (903,073 acres), largely consists of low-grade grazing lands, salt plains, and rough mountain lands. In Kansas the chief grasses on these unfarmed open lands—the short grass country—are buffalo grass, gramma or mesquite grass, bunch grasses, and some sand grass, usually forming a tough sod except where the soil is too light and sandy or the surface too rocky. It so happens that where the soil is too sandy to sustain a sod there is little erosion, the water being absorbed. (Fig. 3.) The sod even in rolling country very largely restricts erosion. On the upper waters of the Canadian River and the Cimarron River in the panhandle country and the high plains of New Mexico, the prevailing grasses are the short buffalo grass and mesquite grass. The grasses which occur on the breaks, chiefly broomstraw (Andropogon), occur in bunches and tussocks, and these largely occupy the thin soils which cover the hills.

Erosion.—While without doubt there has been material increase in the erosion of soil from the cultivated lands on the rolling portions of the lower part of the basin of the Arkansas River, it is doubtful if the

FIGURE 7.—Badly eroded range lands, southeastern Kansas, Arkansas River Basin. Eroded lands in the Permian formation (the Vernon silt loam) in Berber County, Kans. There are extensive areas of this soil type through this portion of Kansas and extending over into Oklahoma, largely on the watershed of the Medicine Lodge River. But similar rough and eroding lands occur in the Neosho and Verdigris River drainages. Better range practice is needed to prevent great enlargement of this devastated area. Trees can be grown upon parts of this land as is shown by the specimen in the foreground of the figure and they should be planted on slopes where the gradient is such that a sod of grass will not hold. (Photo, Bureau of Soils)

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FIGURE 8.—Abandoned farm land restocking to trees, Arkansas River Basin. A typical hilltop abandoned farm and field restocking to trees in the Ozark province. Restocking now taking place slowly could be greatly accelerated by planting, thus reducing the run-off accompanying erosion and increasing absorption of precipitation

FIGURE 9.—Destructive erosion in silt soils, Arkansas River Basin. Advanced stage of erosion on Crowleys Ridge, Dunklin County, Mo., but characteristic of such soils in the flood plains province of both Arkansas and Missouri; loess at the top and coastal plain formation underneath. (Photo, Bureau of Soils)

FIGURE 10.—Caving banks, flood plains province, Arkansas River Basin. Such undermining of stream bank is typical of the lower part of Arkansas River and is constantly taking place. It is a result of the high silt burden and the slackened current of the river, building up silt bars and banks at one point, followed by a compensating encroachment on the river bank at another point

increase from this source is nearly so large proportionately as the increased waste in soil from the red hills of the Permian formation in the river breaks through the high plains country. (Fig. 2.) This has very largely been due to overgrazing, to the tramping out of much of the grass by numbers of cattle, and to the destruction of much of the sod through close grazing, particularly during unfavorable seasons. Close grazing likewise has greatly lessened the amount of seed which is produced and has curtailed reestablishment of new plants as old stools died after a normal period of life. In places throughout the panhandle and adjacent country there has been some slight compensation for this injury to ground cover of grass in the spread of the mesquite tree. This tree during the past 50 years has rapidly pushed its distribution to the northward, probably being spread by cattle which feed upon but often fail to digest the beans. Although it does not afford nearly as much protection to soil on the rolling surface in the plains country as is given by grass, it has some protective value, and under the conditions that now obtain its spread is beneficial.

There is much erosion taking place from the upland cultivated lands, especially those which are hilly or quite rolling. The Mangum dike (terrace) is being employed to reduce this erosion, particularly on the land on which cotton is cultivated in Arkansas, and its use has extended into eastern and middle Oklahoma. Its use, however, is by no means general. The rolling lands in clean, cultured crops not so protected are subject to excessive erosion, particularly under the heavy rains which characterize the summer precipitation of eastern and middle Oklahoma and the adjacent parts of Kansas. There is excessive erosion from the worn grazing and farming lands of the upper and hilly part of the Neosho River Basin in Kansas, and the run-off is accelerated as a result. The same situation exists in Barber and adjoining counties in Kansas. (Fig. 7.) It may be said that practically all of the solid burden of the White River (Table 5) represents material eroded from the agricultural land and from roads and ditches, very little coming from woodland or other sources. The greater portion of the turbidity contributed by the Ozark province of the main Arkansas is from like sources.

In the Ozark province the cultivation of many hillside farms has been abandoned during the past decade. In most cases these farms have been sold to timber companies who have purchased them to acquire small areas of timberland or to secure rights of way. The open land on such farms, however, is no longer cultivated, and erosion of soil is greatly accelerated. As a rule, if old pine trees are standing near by the open lands begin to restock to trees after a few years. but if these farm lands which are no longer cultivated are in a hardwood region restocking to trees takes place very slowly. This natural restocking could often be supplemented most advantageously by planting trees. (Fig. 8.) There are certain soil types, such as the silty soil of Crowleys Ridge, which erode most destructively when located on a slope unless cultivated with very great care. Frequently when erosion of such soils becomes so rapid that washes or gullies begin to form the land is no longer cultivated or protected. This neglect may be followed by its total destruction for farming purposes through the formation of enormous gulches. (Fig. 9.)

Erosion of uplands is of three kinds:

1. That from woodland, which can be largely prevented.

2. That from farm land and the range country, which can be materially reduced.

3. That from "breaks" along streams, from river hills, from arroyos, gullies, etc., so deficient in vegetative cover that constant erosion is taking place. While it may not be possible to prevent this or in some locations even to reduce it, steps can be taken to prevent increase in the amount of erosion material from these sources.

TABLE 5.—*Approximate silt burden contributed by different portions of the basin of the Arkansas River*

	Tons of silt	Per cent	Approximate tons per square mile of basin	Approximate average annual rainfall
White River	2,851,000	11	105	46
Main Arkansas River:				
In Ozarks	[1] 2,138,000	8	114	45
In plains	[2] 5,014,000	20	275	26
In mountains	(3)			24
Total for main Arkansas	7,152,000	28		
Canadian River	[2] 10,927,000	41	275	21
Cimarron River	[2] 5,464,000	20	275	20
Total for Arkansas basin	26,394,000	100		

[1] Estimate based upon the figures for the White River.
[2] Silt burden of upper Arkansas distributed among the three streams on the basis of area.
[3] Very little.

In the consideration of this table it must be borne in mind that the three plains streams are extremely small and are dry for some months each year. The proportionate amount of water which they carry (see table on page 727) even at flood period is relatively small considering the size of their basins. Also there is no run-off and consequently no erosion of soil from much of the plains. Erosion consequently from limited areas on the plains is very high, probably amounting to more than 1,000 tons a year per square mile.

Erosion of soil may be considered a symptom as well as a pernicious result. In regions where erosion has increased until it is now far greater than formerly, it is a symptom that more flood water is now finding its way directly into the streams over the surface of the soil than through the medium of internal channels; it is a symptom that the soil is not absorbing with the same readiness as formerly. If this increase in erosion is excessive, it indicates that for the same amount of rainfall there is a greater run-off and consequently higher flood crests than formerly.

Erosion of soil is a pernicious result through the loss of soil, especially agricultural soil, which is difficult to replace. It represents the loss or the deterioration of the basic capital asset which so largely determines national weal. It indicates added detritus to stream waters; sand beds in stream channels to be removed only by costly dredging at public expense; gravel bars spread over alluvial lands, the productivity of which is impaired or destroyed; silt deposit in reservoirs, the storage capacity of which can not be restored.

The turbidity of the waters of the streams of the Great Plains are due to the fact that their courses run through treeless regions of sparse vegetation and that at times these streams are fed by concentrated though, on the whole, scant rainfall. Erosion and the enormous fluctuations in flow which mark the streams of the Great Plains are particularly important in connection with engineering problems of these streams, but also have a significance in the silt burden and deposits of their lower reaches.

A stream seldom raises the bed of its ordinary channel through deposit of silt, but in case it is unrestricted in flooding its emergency channel or its flood plain the flood plain is gradually built up by a deposit of silt and sand which takes place whenever the current is checked. These deposits form the alluvial lands. When the emergency channel is so constricted that these normal deposits of silt can not be made the excess burden of silt is deposited over alluvials lower down the stream, or it is deposited at the mouth of the stream where the river current slackens. As a rule, if a stream is bearing the maximum silt burden which is possible for its velocity, silt will be deposited whenever there is any slackening of the current. Consequently when the stream current slackens as its waters spread out over the flood plain the heaviest deposit of silt takes place close to the stream's bank and results in building up this portion of the flood plain at a more rapid rate than those portions at a greater distance.

The rate of this erosion has been increasing, and it is the increase with which we have to deal. A great portion of the silt burden of the plains streams and of the burden that the Mississippi River receives from the streams is normal and can be materially lessened only by bettering natural conditions. Such, however, is not the case with the silt burden of streams which flow through regions originally wooded, the turbidity of which has now become unduly heavy. Much can be done on these streams to lessen erosion, and as has been pointed out, lessening erosion means lessening surface run-off and reducing the flood crests. It is in part a problem of better agriculture, maintaining land in better tilth, of terracing, of more cover crops, of the incorporation of more humus; in part a problem of the better use of land, of maintaining certain classes of soils or slopes in grass and retaining other lands continuously in timber.

In those regions which were originally forested, erosion is a well-defined index of accelerated run-off of surface water. From the examination of stream-flow records of the United States, it is concluded that forest cover has little influence upon stream regimen, where the soils are of sand and gravel, and where there is a very large lake surface. And this conclusion is borne out by using erosion as an index. The presence or absence of forest is considered to have but little influence upon stream regimen or upon floods of streams in such sandy regions within this basin.

Erosion from the "breaks."—Notwithstanding the limited annual rainfall in the belt in which the breaks are located, only from 20 to 32 inches, the fact that the larger part of it falls during the spring and summer months and that the character of this rainfall is often of the most concentrated type results in high erosion on slopes wherever the naked spots are exposed to water action. Under natural

conditions much of these lands were covered by a close sod of buffalo, gramma, and other grasses, while Andropogons formed tussocks on the steeper portions. With the development of the country and the extension of the cultivated area, the sod of the native pasture grasses has deteriorated, particularly on stony and steep sites, a class of sites employed only for pasturage. As a rule such rough lands as are not cultivated are subject to such close grazing that excessive erosion is taking place. Erosion is also active in the fields, especially with those classes of crops which demand clean cultivation, such as cotton, corn, soy beans, and the sorghums.

In the western part of the province, moveover, there are extensive areas of unconsolidated upland soils. These soils as a rule would easily absorb the limited rainfall of this region. In fact there are large areas from which there is no run-off of surface water, all of the rainfall being absorbed, but on account of their unconsolidated nature and the frequently concentrated character of the precipitation during the summer months, there is often an excessive run-off near the streams and through dry gullies, which converts these dry gorges or small streams into raging torrents and occasions enormous erosion of the soft rocks which form portions of their beds and walls.

Erosion of stream banks.—The largest amount of silty material taken from the banks of the Arkansas River is a transient burden which is eroded from one hollowed bank or from a bar at one point and farther down is deposited upon a rounded bank or goes to build up another bar. This condition is well shown by the conditions along the bank of the river below Little Rock. "It is estimated that the eating and caving of the shore below Little Rock averages 7.64 acres per mile of river channel every year as against 1.99 acres per mile above Little Rock." It is evident that if this corraded earth were not replaced the alluvial lands below Little Rock would rapidly shrink in area, but this is not the case. They lose at one point but accretion takes place at another. The changes are due to the heavy silt burden of the river in this stretch. On account of this excessive burden, rapid deposit take place when the river enters the stretch of low gradient below Little Rock. Such deposit causes an adjustment or change of current resulting in a loss of stream banks at some point below. Thus change and exchange are constantly in progress in that reach of the river at which the stream for its velocity reaches the point of silt saturation. The earth which is corraded from the banks (fig. 10) is replaced by an equal amount brought down from other sources.

CONDITION OF FOREST

The upland forests of the basin are of three types: (1) In the Ozark region they are in part pine and broadleaf, and in part exclusively broadleaf. (2) The woodland of the plains country which lies to the west of the heavily timbered Ozark belt, however, is entirely broadleaf. The greater portion of the plains section is treeless, with the exception of strips of timber on the alluvials and bordering the watercourses, and the scrubby chinquapin oaks, walnuts, and mesquite on many of the sand hills. (3) The forests at the headwaters are coniferous, chiefly of pine and spruce, the woodland also being largely coniferous, open stands of pinon and cedar.

FIGURE 11.—Burned-over spruce lands, headwater province, Arkansas River Basin. Burned Engelmann spruce lands near Marshall Pass, high mountains of Colorado. The run-off of storm water and snow melt is rapid from such lands. Natural restocking takes place very slowly and only in the immediate vicinity of the green seed-bearing timber

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FIGURE 12.—Burned-over spruce lands, headwater province, Arkansas River Basin. Head of gully formed in burned-over forest lands, due to rapid run-off as a result of the destruction of the forest and the protective forest humus

230—2

FIGURE 13.—Roots of trees exposed by overgrazing. Roots of trees exposed by excessive pasturage resulting in extreme erosion in hillside lands on the basin of the Mississippi River. While this condition is an extreme one it typifies the tendency wherever woodland is subject to overpasturage. (Courtesy of C. C. Deam, State Forester of Indiana)

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(*A*) *Lumbering.*—A large part of the old timber has been cut in the lowland province east of Little Rock, but since fires are not serious on account of the moist sites abundant stands of young trees have replaced the old timber as it has been cut. There has been no change in surface conditions as a result of this.

On the whole, lumbering has not seriously affected the forest conditions in the Ozark province. The best pine timber has been largely cut and on many of the pine lands practically all of the pine has been taken, leaving only the smaller oaks. This is the most serious injury, from the point of timber supply as well as stream regulations. The humus on such areas has deteriorated, there being much less humus produced by the scrubby oaks than would be formed by heavy stands of pines. On the bottom lands the cutting of the hardwood timber is seldom followed by fire. As a result there is generally a good replacement and no material change in the surface conditions.

(*B*) *Fires.*—Fire has done and still is doing great injury to the surface condition of the upland forest of the Ozark province in both pine and broadleaf stands, in destroying humus and in suppressing young growth, especially of the pine which sprouts only feebly. The influence of the two national forests in the Ozark belt, however, is decidedly beneficial, although it has not yet reached a point at which the value of the forest is appraised as more than neutral in watershed protection. Not only are fires less frequent in the national forests, but they are becoming less frequent in the adjacent privately owned woodland; but fires still occur so frequently that the layer of humus is insufficient to add material storage. Fire is not a serious problem in the woodland of the plains province, but in the headwaters province heavy stands of coniferous timber have in the past been destroyed by fire (fig. 11), the land has failed to restock, and deep gullies have formed (fig. 12), greatly reducing absorption of snow melt and storm waters. The protection afforded through the national forest administration in the headwaters province now tends to reduce the possibility of such fires, even on privately owned lands, but the protection of these lands is still not by any means thoroughly effected.

(*C*) *Grazing.*—Although grazing in the Ozark province has up to recent years had material influence in extending the forests, it is now having an injurious influence upon the condition of the forest. At the present time much of the woodland in this province is overgrazed, with the result that there is considerable suppression of replacement, and much erosion is induced as a result of the exposed surface. Figure 13 shows an extreme case of this kind, but it indicates the susceptibility to erosion of all woodland which is subject to excessive grazing. The woodland areas of eastern Oklahoma are frequently excessively grazed, being used as pastures or being attached to pastures. Wherever the slope of the surface is at all steep, erosion is excessive on account of the impairment or destruction of the vegetative cover.

In some places excessive grazing is also extremely detrimental to privately owned coniferous woodland in the headwaters province through the suppression of replacement by trampling of stock. The forest lands on the headwaters are seldom grazed to excess, since they are largely within national forests.

(*D*) *Drainage.*—Drainage is an important problem only in the eastern flood-plain province. Levees and drainage ditches have been constructed on the Black River below Poplar Bluff with the object of drainage and protection against floods. Although considerable land has been reclaimed by this means, channels as a rule are unable to carry the water of heavy storms which spreads out over the adjoining land and does much damage. St. Francis River is protected by levees built by the Interriver and Mingo drainage projects. Much work still remains to be done, however, to protect the delta land on both streams from flood waters. The city of Poplar Bluff secures its water supply from the Black River. It is significant that most of the drainage ditches along the Mississippi River drain from the river, thus indicating that the land near the river has been built up by deposits of sediment to a higher level than that along the old channel of the Mississippi River, now occupied by the St. Francis River, into which these ditches lead.

TABLE 6.—*Protective value of watershed, Arkansas River*

[Area of basin, 188,342 square miles]

RATINGS[1]

Class	Square miles	Per cent of area	Unit protective value	Proportionate protective value
Soil:				
Sands	16,374	0.087	1.00	0.037
Silts	103,632	.55	.50	.275
Clays	20,116	.11	.75	.082
Stony	41,905	.22	1.00	.220
Alluvial	6,485	.033	1.00	.033
Average				.6975
Physiography:				
Level and rolling	110,643	.59	1.00	.590
Very hilly	51,303	.27	.50	.135
Mountainous	26,569	.14	.50	.070
Average				.795
Precipitation			.75	.75
Character of cover:				
Forest	43,144	.227	.75	.170
Clean cultivated crops	9,242	.049	.50	.024
Small grain	10,986	.058	.70	.041
Grass and grazing	122,943	.655	.75	.499
Unprotected and waste, naked	2,200	.011	.50	.005
Average				.739
General average				.737
Total	188,342			

[1] A rating of 100 is regarded as representing the optimum condition for the site or factor being considered

CRITICAL AREAS

There are certain areas in the basin where the equilibrium between the various factors of soil, slope, precipitation, and cover is so nicely adjusted that any radical change is followed by aggravated loss of soil or by the entire removal of the top soil accompanied by accelerated run-off. Such lands are called critical areas. They may be lands which were originally in grass or in prairie soil. They may have originally been wooded. At any rate under natural conditions,

whether in sod or in brush or in trees, the soil very largely remained in place and run-off was not being accelerated. These are lands which it may be necessary to maintain in grass or to maintain in woods, or which, if cultivated, must be level-terraced and given the most careful attention. They are lands, in fact, the unrestricted use of which may jeopardize the value of other lands or other interests of far greater value. They are lands the permanent producing capacity of which can be maintained only by limiting their use.

Critical areas fall into three classes:

1. Those lands upon which the natural equilibrium has not been disturbed and where factors of the site are essentially beneficial in regard to streamflow and flood conditions. That is, erosion of soil is slight; storm water is largely absorbed, and spring flow is abundant or at a maximum for the site. These lands are classed as having a beneficial influence.

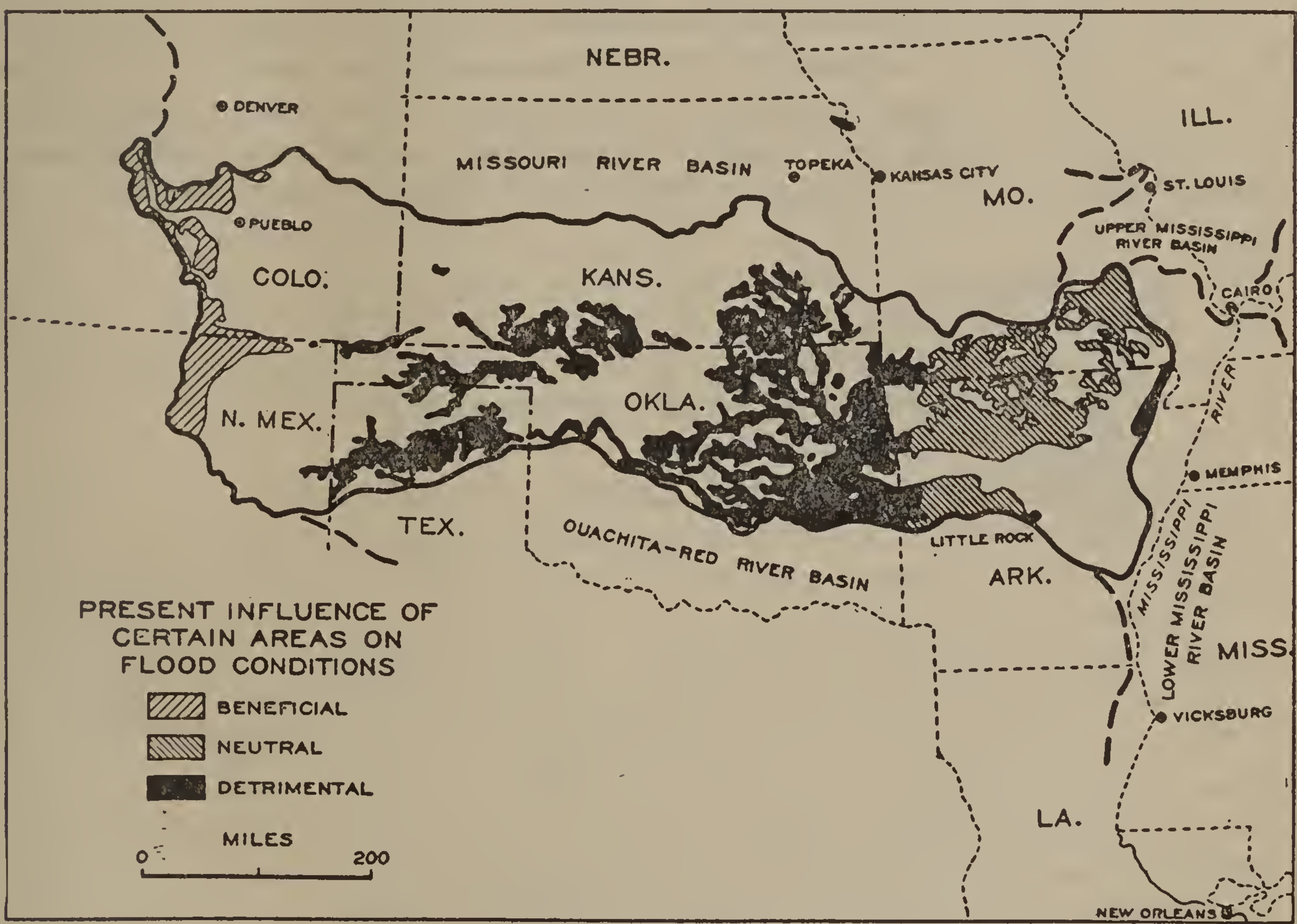

FIGURE 14.—Arkansas-White River Basin

2. Those lands upon which the natural equilibrium has been disturbed and the productive functions impaired but not sufficiently for the lands to be regarded as having a deleterious influence upon stream flow and flood conditions. These lands are classed as having a neutral influence.

3. These lands upon which the natural equilibrium has been disturbed to such an extent that the lands are now having an unfavorable influence upon streamflow and in augmenting flood conditions through excessive erosion of soil and through high and slightly impeded run-off of storm water. These lands are classed as having a detrimental influence.

The total area of critical lands on the Arkansas-White River system is about 38,164 square miles, of which 11,352 square miles are classed as detrimental; 18,306 square miles as neutral; and 8,506

square miles as having a beneficial influence. The lands classed as detrimental embrace a large portion of the "breaks" and include the rolling and hillside farm lands in the eastern portion of the plains province and within the Ozark province where considerable areas of such lands of marginal agricultural quality have been abandoned. The neutral lands embrace those portions of the national forests and similar lands, particularly within the Ozark province, which until within the last few years have been badly ravaged by periodic fires, and have been under protection for too short a time to have recovered from this prolonged unfavorable influence. The beneficial lands are those national forests and similar lands, particularly within the headwaters province where excellent surface, and humus conditions prevail and which are exercising a highly beneficial protective function.

Critical lands may be in forests, in grass, in cultivation, or they may be untimbered wild lands subject to change by human agency.

Critical forest areas.—There are five types of critical lands on the basin of the Arkansas River. Three of these are critical forest types; two are critical herbaceous cover types. An area is designated as "critical" which in its native condition bore a vegetative cover which exercised an important protective service in promoting soil absorpton of storm water, in reducing run-off of storm water or snow melt, or in lessening erosion of soil. The removal or destruction of this cover has a deleterious influence. In case this cover is forest, woods, or large shrubs it is designated as a "critical forest type"; other protective vegetation, usually brush and grass or grass alone, is designated as "critical herbaceous cover type."

Forest cover types.—In the Ozark province there are extensive areas of land largely in woods but partly cleared, which are covered with a mantle of chert, and which on account of this cherty surface and the porous subsoil due to the fissured limestones and shales, absorb heavy rainfall excellently. These soils on account of this excellent absorption are still usually saturated from the winter rains at the time when the heavy late spring rains take place. Some of these areas, including the barrens and so-called knobby sections, have a level or gently rolling surface. Forest cover nevertheless has high value on these lands, not in promoting absorption which already freely takes place, but through the humus which can be developed to an additional depth of from 1 to 2 inches with a supplemental thick layer or leaf mold and litter on top. The water storage capacity of these lands can through the medium of this layer of humus be materially increased in carrying heavy precipitation. Erosion of soil is not such a serious factor from the cherty lands, although erosion is considerable from certain parts of the Ozark region, and is high from those areas which have silty soils and which are not protected by chert, largely the farming soils and roads. The larger part of all lands at present in woods in the Ozark and Ouachita regions should be retained in woods, although there still remain areas which are suitable for farming purposes and which should be available for cultivation when the economic situation will permit it. Forests should be reestablished on certain areas which have been cleared. Additional extensive areas in this belt should be incorporated in public forests, particularly in southern Missouri chiefly on

the watersheds of the Current and St. Francis Rivers; and there should be a large increase in the national-forest area on the drainage of the Arkansas proper as well as on the White River drainage. An additional area of not less than 3,000,000 acres should be added to public forests in these regions.

A second class of critical forest areas embraces the lands on the steeper slopes and bluffs along streams of eastern Oklahoma and Kansas. A considerable portion of this land is still in timber, although the stands are prevailingly of the open woodland type.

A third class of critical forest areas embraces the coniferous forest lands in the headwaters province, both the heavy forest and the woodland types. These lands are important in protecting the upper watersheds of streams such as the Purgatory River and other streams in the region which are subject to cloud-bursts and which

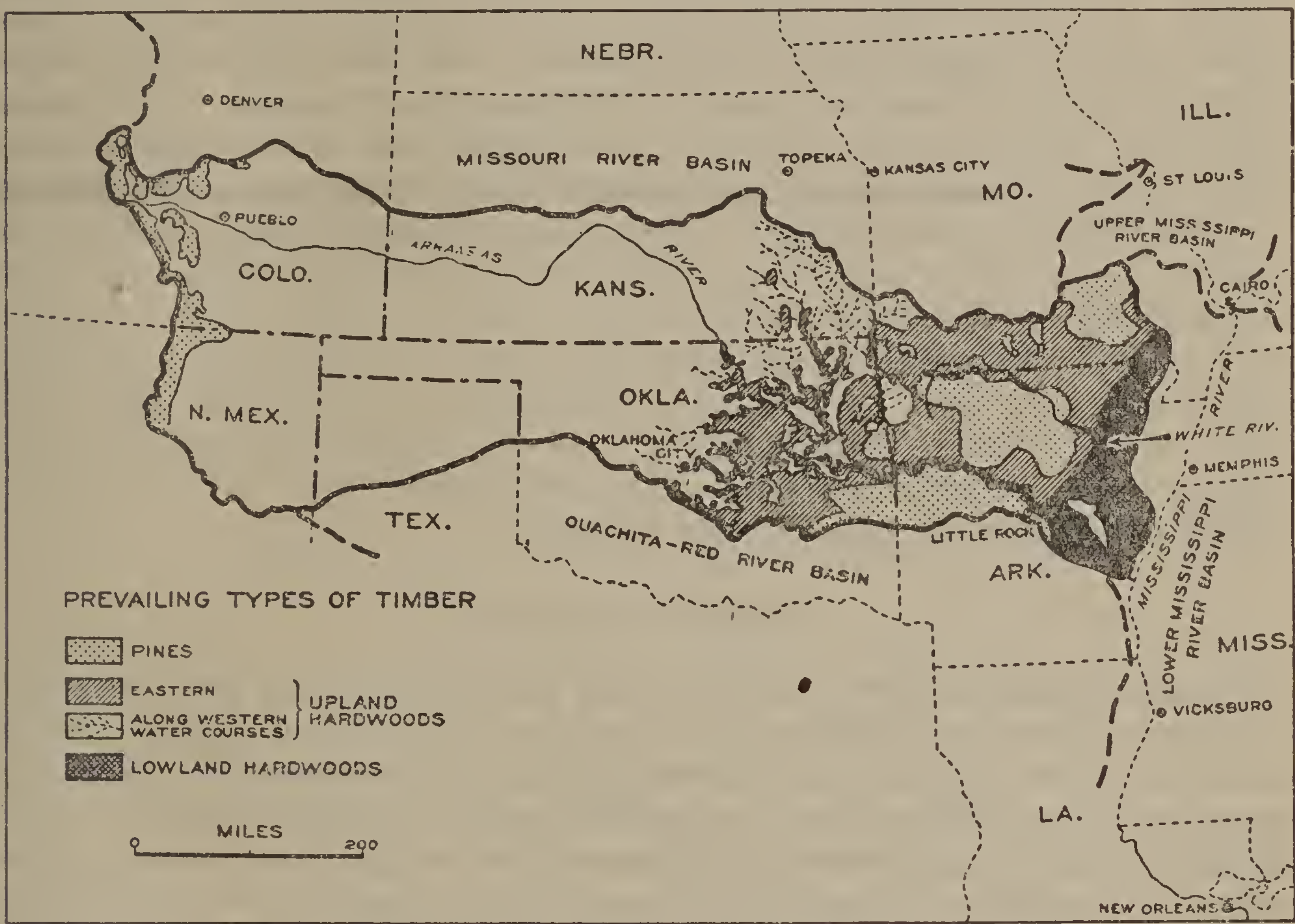

FIGURE 15.—Arkansas-White River Basin

have been devastated by destructive floods, such as the Pueblo flood of 1921 and the Purgatory River flood of 1904.

Cover types other than forest.—A fourth class of critical lands embraces the sparingly wooded, brush-covered, grass-covered, or even partly naked slopes of the "breaks," the gorges of the main rivers and of their tributaries throughout the high plains region. These are combination brush and grazing areas in large part naked. The natural adjustment of vegetation hangs on a slender balance throughout this region and on these slopes. This is due to the long spells without rain interrupted by downpours of the most torrential character. Any slight disturbance of the balance in this tension zone may result in the entire destruction of the protective cover of herbage which nature unaided may not be able to reestablish—and every exposed surface in this region on suitable soil is subject to the most excessive erosion. Erosion indicates that complete and

proper absorption is not taking place. These critical areas embrace considerable stretches of grass land around the edges of the plateau as well as the slopes of the gorges themselves. Figures 14 and 15 show the first and second stages of an arroyo branching from one of the main streams of the "breaks" in the high-plains region and extending its head back into the surface of the plateau. They show also the influence of the grass cover in retarding the encroachment of the arroyo. On account of the severe climatic conditions which almost preclude reestablishment of the natural vegetation on sites which have become denuded, it is desirable that particular effort should be made to prevent denudation from taking place on such slopes in this region.

Considerable areas of rough land in northeastern Oklahoma and in middle-eastern and along the southern edge of Kansas, particularly on the Neosho (fig. 7), Cottonwood and Verdigris Rivers, are in a similar class, the conditions being such that any unfavorable factor may upset the equilibrium and destroy the sod which has a precarious existence, and by doing so increase both erosion and run-off. With this class may be included the considerable area of naked farm land which has been abandoned chiefly within the Ozarkian province.

A fifth class of lands are the watersheds of small streams within the treeless region upon which reservoirs are located for storage purposes. On account of the high-silt burden of these streams, reservoirs silt up rapidly. In order to prolong their life, it is necessary that precautionary measures be taken to reduce erosion from the surface of their basins. Even in advance of the construction of such a reservoir protective measures should be inaugurated with a view to prolonging its life and period of usefulness.

RECOMMENDATIONS

Forest lands.—There should be an increase in the area of public forests within the Ozark dome region (the rough portion of the Ozark province to the northward) of not less than 3,000,000 acres upon both the White River watershed and the main Arkansas. The small area of State forests in Missouri, amounting to about 41 square miles, is insignificant in comparison with the magnitude of the problems of stream protection and forest management which must be solved in this region. In Arkansas not only should the area within the existing boundaries of the national forests be consolidated but these boundaries should be extended so as to include extensive areas at present outside. Not less than 1,000,000 acres should be added to the national-forest area in the State of Arkansas. There is, likewise, room in the State for an extensive series of State and other local forests, not only in the Ozarkian province but within the lowland province as well.

In Oklahoma, where there is a small State forest and game preserve in McCurtain County, there should be on the watersheds of the Red and Arkansas Rivers not less than 1,000,000 acres in public ownership within the general Ouachita Mountain region, of which about 400,000 acres should be upon the watershed of the Arkansas River. The results to follow such an extension of public ownership would be a higher earning power for the hardwood and pine lands of this

region and a resulting betterment in the humus and soil conditions throughout the region as a whole. On private lands prevention of fire is the acute problem throughout the entire Ozark region. There seems to be urgent need for extending special aid to this region under the fire prevention cooperative features of the Clarke-McNary law.

In the woodland areas of Oklahoma, southeastern Kansas, and Missouri fire is not an important problem. The forest areas are too limited in extent and wood on the whole is too valuable for fires to be allowed to run at large. The inflammability is not great and the protection received from resident owners as a rule is usually adequate. There is, however, urgent need for better control of grazing in this woodland, since it is on account of excessive grazing that the humus in these areas has been reduced or destroyed, and the underbrush cover largely eliminated, with resulting higher erosion and lowered absorption of rainfall. (Fig. 13.)

In Kansas and Oklahoma, as well as in other States, there should be developed an extensive system of small public forests and parks located particularly on the steeper wooded slopes along and near the stream. These areas on the whole will be too small to be considered by the National Forest Reservation Commission. They should be in the class of local or State parks and forests. Furthermore, it is desirable that there be extensive planting of forest trees of those kinds which can be established and which will grow under the arduous conditions of the plains in middle and eastern Kansas and middle Oklahoma. Planting is especially desirable for the protection of lands under conditions where the slopes are so steep that adequate protection can not be assured by a grass sod. There is ample justification also for planting on other portions of the basin, such as for the checking of gullies on the silt soils of Crowleys ridge and in localities where cleared lands are disastrously eroding. The possibilities of planting in middle Kansas and to the westward are determined by the possibilities of irrigation. While the most successful nonirrigated plantations were made on sandy soils, undoubtedly species can be found which will grow on the physiologically drier silty and clayey soils as well. There should also be a great extension of windbreaks throughout this region, especially on the plains and high plains section and on all rolling lands. Special provision should be made for carrying forward such a program under section 4 of the Clarke-McNary Act. At least 10 per cent of the area of irrigated farms in the high plains and foothills region should be maintained in windbreaks and plantations of trees.

In the headwater region a considerable extension of the national-forest area is desirable, not so much on account of any influence that these forests may have upon major floods in the Mississippi River Valley, as to provide protection against the local floods resulting from cloud-bursts and to hold back the débris which is frequently swept into the valleys with such floods. There should be additions of 594.7 square miles to the Leadville, Pike, Cochetopa, and San Isabel national forests of mountain lands of high protective value.

Agricultural and grass lands.—For the plains and prairie region of the basin of the Arkansas a rigorous policy should be adopted

having for its object the dual purpose of affording the largest amount of grazing compatible with maintaining the most effective protection to the surface of the country. The rapidity with which the ravines and hollows eat back into the soft stone and unconsolidated soils which surround the "breaks" requires that strenuous methods are put into practice to prevent a rapid enlargement of the rough land surrounding the edge of the "breaks." (Figs. 16 and 17.) The intrusion of a deep ravine into a hitherto level area of farming or grass land means that its earning value is entirely gone. From a gully it passes to a gorge and from a gorge in a few years to a canyon. At Amarillo, Tex., on the basin of the Canadian River, with an annual rainfall of less than 21 inches, more than 9 inches has fallen within a period of 24 hours. Similar concentrated precipitation is the rule throughout the Panhandle country. Such concentrated precipitation on soils deficient in cohesion, unprotected or scantily protected by any class of vegetative surface cover, results in rapid and utter ruin if so situated that erosion can take place.

There is likewise opportunity for much betterment in the method of handling tilled lands. The eastern portion of Oklahoma, particularly the southeastern, has rapidly developed agriculturally, and is still almost a virgin soil. In its early agricultural history following the use of the land for grazing, small grains were the important crops. Small grain gave way in part to corn. The extension of the cotton-producing area high up into eastern Oklahoma and the Panhandle of Texas has in the past few years resulted in radical changes in the agricultural system. Corn and cotton and clean-tillage crops now largely prevail to the exclusion of small grain and hay. On the level lands which form the crests of the intervals little erosion follows this class of tillage. On the rolling lands, however, which extend in some places for great distances back from the streams, erosion has been excessive. There has been very recently a general adoption of dikes of the nature of the Mangum terrace in handling clean-tilled crops in this region. So far as this goes it has been beneficial, but much still remains to be done along this line. Not only should these check-water systems be in universal usage where the surface is rolling, but their employment should be accompanied by a more general use of cover crops, together with definite systems of rotation and with hay or a nontilled forage crop of some kind alternating with a clean-tilled crop. On the steeper slopes where in spite of check-water dikes, like the Mangum terrace, some erosion will continue to take place level terracing may be necessary. The advantage of the level terrace will be not only to hold all of the soil, but to hold all of the water—a most beneficial result in a section which frequently suffers from ruinous droughts. While the general character of the precipitation is such that cover crops for the purpose of reducing erosion of soil are of less value than farther south and east, where the Gulf type of precipitation prevails, nevertheless there are heavy rainstorms during the late winter and early spring before the summer crop is established, which results in enormous damage to soil and contribute large amounts of earth to the rivers.

Betterment in agricultural practice should be secured largely through the instrumentality of the county agents and through State official agencies. This phase will be largely a matter of adminis-

FIGURE 16.—Initial stage in gully, high plains province, Arkansas River Basin. The first break in the sod in the high plain country due to the eating back of the head of a prairie stream into the level of the plateau. Grass still covers the slope where the surface has given away. (Photo, Bureau of Soils)

FIGURE 17.—Advanced stage in gully, high plains province, Arkansas River Basin. Advanced stage in the progress of a stream head in the high plains country in eating into the plateau. Unless the advance of the gully is checked the farm lying beyond the present stream head will soon be engulfed. (Photo, Bureau of Soils)

FIGURE 18.—Windbreak, plains province, Arkansas River Basin. Shelter belt of cottonwood protecting orchard on broken plains of middle Kansas. Every farm in the plains region should benefit from such a protection

tration through the instruction of individual landowners. It will be of prime benefit to the individual owner and to the local community, but the influence upon soil conservation through better absorption and storage of rainfall and through reducing stream siltage will be significant. The investigation of the problem of erosion from agricultural and naked lands must be largely conducted locally, since it varies widely on different soil types and under different types of rainfall. In particular, investigations should be conducted relative to the establishment of vegetative cover on the breaks and on the hilly lands in eastern and southern Kansas, which are sources of large amounts of river silt and the origin of local floods, particularly on such streams as the Neosho and the Cottonwood, the upper parts of the basins of which are extremely hilly, the run-off of these streams from this hilly, largely naked surface being excessively flashy.

Sources of betterment in water storage.—There are three sources of betterment which can be employed to promote water storage. Two of these pertain directly to soil cover to secure increased absorption of rainfall by the soil. One of the direct sources is the development to its maximum absorption efficiency of the forest humus. The other is increasing the absorptive capacity of naked land. The third source of betterment relates to the protection of reservoirs for the storage of flood waters, particularly for irrigation.

Increasing the absorption and storage capacity of forest soils.—Table 7 shows that, having a basin which occupies 15 per cent of the entire Mississippi River drainage, the Arkansas River in the period from 1912 to 1927 contributed, on an average, 14.2 per cent of the waters of the major Mississippi River floods at Arkansas City, Ark.

During March and April, 1927, the rainfall in the Ozarkian province amounted to 12.94 inches. The rainfall on the entire basin for this period averaged 7.19 inches. Of the total rainfall a little less than one-half fell on 72 per cent of the basin and a little more than one-half on 28 per cent. The Mississippi River on April 21 at Arkansas City had a stage of 60.5 feet.

Table 8 was constructed from the records of the Board of River and Harbor Engineers. It shows that during this flood the Arkansas and White Rivers contributed 40.6 per cent to the maximum stage of the Mississippi River at Arkansas City, Ark. The upper tributaries of the main Arkansas River, however, contributed a total of only 2.3 per cent to the flood waters of the Mississippi River at Arkansas City, Ark. The main Arkansas River contributed 32.2 per cent, the lower Arkansas River within the Ozarkian province contributed 29.9 per cent and the White River contributed 8.4 per cent. Thus a total of 38.3 per cent of this stage of the Mississippi River was contributed by the Ozarkian province occupying less than 2.5 per cent of the entire basin of the river. Theoretically this represents 23 feet of the river stage of 60.5 feet.

The Mississippi River on April 21, 1927, at Arkansas City had a stage of 60.5 feet, its maximum stage. On this 60.5-foot stage the Ozarkian province contributed 38.3 per cent or, theoretically, 23 feet.

Accepting Wollny's figure of the water absorptive capacity of humus as being twice the weight of the humus, a figure which has been verified by a test recently made, the humus on the Arkansas River has approximately the following storage capacity for rainfall:

One square foot of air-dried humus 1 inch thick, which can be regarded as the possible increase in the humus on this basin as a result of complete protection, weighs 315 grams. This weight of humus will absorb water to the amount of twice its weight or 630 grams, or 630 cubic centimeters.

One inch is equal to 2.54 centimeters, or 1 square inch is equal to 6.45 square centimeters, or 1 square foot is equal to 144 by 6.45 square centimeters; 1 square foot is equal to 928 square centimeters.

Six hundred and thirty cubic centimeters divided by 928 cubic centimeters gives 0.68 centimeter of water, the equivalent of 0.2677 inch. That is, a layer of dry humus 1 inch thick, including quite a bit of duff and litter, might absorb 0.2677 inch of rainfall and hold it. Approximately two-thirds of the Ozarkian province of the Arkansas Basin is in forest. Consequently, the amount of rainfall which might be held by the addition of 1 inch of humus to this region would be two-thirds of 0.2677 inch, or 0.1785 inch.

The area of the Ozarkian province is 52,808 square miles (including woodland area within the near-by plains). A precipitation of 0.1785 inch over this area amounts to 21,875,000,000 cubic feet,

$$\frac{5{,}280 \times 5{,}280 \times 52{,}808}{67.2}$$

or 1 additional inch of humus might store 22,000,000,000 cubic feet of water. At flood crest, April 21–23, 1927, the discharge of the Mississippi River at Arkansas City, Ark., was 1,900,000 cubic feet per second, the river stage being 60.5 feet. If the river stage were reduced to 55.55 feet, there would be withheld a flow of 158,000 cubic feet of water per second.

If an additional inch of humus would store 22,000,000,000 cubic feet of water, this storage would withhold 158,000 cubic feet for a period of about 39 hours, or 1 day and 15 hours, which would usually cover the period of maximum flood crest.

Increasing the absorption and storage capacity of naked lands.—There are two classes of naked lands in the Ozark Basin. One is the large areas of farming lands cultivated occasionally or abandoned and no longer cultivated at all, largely on slopes, and, as a rule, representing marginal farming conditions. The acreage of such lands has largely increased during the past 20 years as a result of the change in living standards and the decrease in rural population following the migration to the cities. The other class of naked lands consists of "breaks" and unclothed hills lying along the rivers and larger streams, especially in the western portion of Oklahoma and on the southern line of Kansas.

It is a well-known fact that naked soils other than sands absorb a far smaller proportion of rainfall during a year than similar soils which are in cultivated crops or in grass or woodland. There are two factors which cause this: One is that a heavy rain falling direct on a silty or clayey soil compacts and puddles the top surface, rendering it largely impervious to the absorption of water and resulting in run-off accompanied by erosion of soil in place of absorption, unless the land is level. Erosion itself is an index that absorption is not taking place and that there is an excess of surface run-off.

This retardation in absorption is further increased on naked sites on account of the deficiency in subsoil water channels which are largely the result of the decay of roots. The soil of grassland and woodland, on the other hand, is permeated by numerous channels of this kind resulting from the decay of roots and rootlets. As soon as capillarity is established between the surface of the soil and the root zone lying immediately beneath the soil, the roots and these tiny aqueducts conduct the surface water into the subsoil, causing it to be absorbed by the subsoil at an extremely rapid rate. The absence of these root channels in naked soils causes such soils to absorb far more slowly even after capillarity has been established, with the result that only a relatively small proportion of each heavy rain is absorbed by a naked soil if on a slope, while on level sites from which the water can not run off the absorption takes place but slowly.

Even in the case of land in crops, absorption often takes place more slowly than in the case of grassland and woodland, because the soil surface may puddle. Although the roots of annual crops afford conductivity and tend to establish lines of capillarity, there is a great deficiency in larger channels resulting from the decay of roots such as is found in any piece of old grassland and in the forest in particular.

The method of meeting this condition is to secure a cover crop of some kind either of grass or of woodland on all naked land. This should apply to the breaks as well as to the farming land. There are in particular extensive areas of land in southeastern Kansas on the watershed of the Neosho River and the Cottonwood River, and farther west on the Verdigris where ample betterment is possible. Erosion, then, is not entirely a problem within itself, but is a problem largely of failure to absorb or deficiency in absorption, and consequently if erosion is reduced greater absorption is secured. The two benefits are concomitant.

The cause of erosion is the failure of a soil in a hilly country to absorb the rainfall which falls upon it. If the rainfall is all absorbed as by a coarse sandy soil, which is largely the case in the sandhill portions [of the basin of the Arkansas River] there is no run-off and no erosion. As the soil becomes finer in texture, more compact and correspondingly less pervious, the rain is not absorbed as fast as it falls and the very smallness of the grains which form the soil facilitates its transportation wherever there is sufficient slope. The difficulty is that a heavy rain, especially a summer shower, on a dry, fine, textured soil quickly puddles the surface of the soil and the absorption of water is checked until the air can be gradually expelled. This takes place far more slowly on the silts and clays than on the open-textured sands.

Reservoirs for the storage of storm water.—The State of Oklahoma has prepared extensive plans for the location of reservoirs for the storage of storm water for the prevention of floods and for irrigation, and the State of New Mexico at present is engaged in the preparation of similar plans which would cover the headwaters of those branches of the Arkansas River lying in the State of New Mexico. Although the streams on which it is contemplated to locate these reservoirs contribute only a relatively small amount of water to the floods of the Mississippi River, such a system of reservoirs would be of benefit in the control of local floods. It would be of prime importance, however, in connection with the location of such reservoirs to secure the fullest protection to the surface of the basins

from which would come the water which the reservoirs are designed for storing. It is patent that the more extensive is the system of such reservoirs the smaller will be the amount of water which these streams contribute to the floods of the larger streams. Eventually the entire flow of these headwater and plains streams—flood flow as well as normal flow—should be stored and used locally for irrigation. Such a system might extend well down into the prairie country, where there is often marked irregularity in the rainfall.

GENERAL SUMMARY

Fire prevention.—Fire prevention is essential upon all forest lands. On the private lands of the entire Ozark region, the need for protection is acute and considerable effort is needed to bring about a consciousness of the damage fires do, and to control the spread of fires in this section. A greatly enlarged effort under section 2 of the Clarke-McNary Act to bring about better control is urgently needed.

Grazing.—Most of the woodland areas are overgrazed and damage is being done the forest through trampling and through making suitable conditions for further erosion. Too heavy grazing is also resulting in changing the composition of the forest by preventing the establishment of certain species.

On grass lands, a balance must be established that will permit the maximum grazing consistent with the maximum protection from erosion through the maintenance of a full and complete sod. Activity by all extension agencies is indicated as needed to bring about a greater consciousness of the necessity for preserving the soil cover.

Forest management.—Proper forest management is essential on all forest and woodlands to preserve the maximum density of cover and the best growing stock, particularly on the areas given to ready erosion. This is of greatest moment in the hill lands and in the "Breaks" region, where injudicious handling of the woods may result in starting erosion where no erosion now exists, or in accelerating that already in progress.

Public forests.—The area in public forests in the Ozark region should be increased by not less than 3,000,000 acres. An additional area of 1,000,000 acres should be added to the national forest area in Arkansas, and not less than 1.000,000 acres should be acquired by the Federal Government in Oklahoma in the Ouachita Mountain region on watersheds of the Red and Arkansas.

These areas should be in addition to the State, county, or other public forests or parks that should be established in those sections and elsewhere, as in Kansas and Missouri.

On the headwaters of the streams in the Rocky Mountain region to prevent floods, sustain the low water flow, and to prevent additional silting and débris coming from that section, nearly 600 square miles of land should be added to the Leadville, Pike, Cochetopa, and San Isabel National Forests.

Reforestation.—Trees and shrubs should be used to hold slopes too steep for grass sod, and on such areas as are already in the process of eroding. In the plains section eroded and denuded areas should be planted to suitable species of trees and shrubs if water is available.

Windbreaks and shelter belts are desirable in the plains section not only for human comfort, but to reduce wind movement and decrease the amount of wind-blown soil. (Fig. 18.)

In the forest regions, tree planting is a necessity on all denuded lands. To further this activity, planting stock should be made available through section 4 of the Clarke-McNary Act.

Agriculture.—Agricultural lands should be so terraced that erosion and run-off are reduced to the lowest possible point. Better methods of tillage, coupled with terracing of all sloping lands, even those with slight slope, will materially reduce the erosion and the run-off. To reach the land operator, greater activity must be manifested by the extension agencies that the importance of good land management may be brought forcibly to his attention.

Engineering.—All too often lands have eroded because of the improper drainage, and this improper drainage has also resulted in unduly hastening the run-off.

The possibility of developing reservoir sites should be worked out with the help of the flood-control engineers, at least in the prairie region. Water storage may be used to augment flood-control works, and the water used to further irrigation enterprises.

Research.—Investigations are needed to determine the best species of plants or trees to be used in this drainage for controlling erosion and building up the humus in the soil, not only along the lower stretches of the river but also in the plains region. For much of the area, the best planting technique must be worked out and the best methods of planting determined.

Investigations are needed in the Ouachita Mountains to determine the best silvicultural treatment to be given the forest to maintain the soil-protective features of the cover at the highest degree of efficiency, compatible with good forest management.

Methods of protection which will insure the quickest suppression of fires that do start must be determined as, also, better methods of developing the existing protective and detection forces.

As a part of the use of land, grazing will always be a feature, but proper grazing management must be worked out for both the timbered and nontimbered parts of this watershed.

Finally, the effect of forests of different degrees of density, of different composition, and of different character upon streamflow and erosion as a whole must be worked out, so that the areas of greatest influence may be given that treatment which will insure their proper management for the benefit of the lower Mississippi River.

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PART VI

FOREST CONDITIONS WITHIN THE RED RIVER–OUACHITA BASIN

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PART VI

FOREST CONDITIONS WITHIN THE RED RIVER-OUACHITA BASIN

INTRODUCTION

Location and area.—The Red River-Ouachita Basin, lying entirely to the west of the Mississippi River and adjacent to, but south of the Arkansas River watershed, drains an area of 88,191 square miles. The watershed of the Tensas River forms the eastern boundary, and the drainages of the Atchafalaya, Sabine, Neches, Trinity, and Brazos Rivers combine to form the southern boundary. The total length of this basin is approximately 750 miles, and the width varies from 80 to 190 miles. Heading in eastern New Mexico at an altitude of nearly 5,000 feet, this great drainage area extends eastward across the Texas Panhandle, through southern Oklahoma and northern Texas into southern Arkansas and northern Louisiana, where it occupies nearly two-fifths of the areas of each of the latter two States.

Topography.—West of Arkansas and Louisiana the Red River Basin slopes almost due east with a slight inclination toward the south. However, upon entering the above-named States the Red River turns sharply southward, and most waters within this portion of the basin flow southeasterly. However, there are many streams in the lower Ouachita River Basin which flow almost due South. Excepting the flat alluvial lands of the river bottoms in the southern and eastern portions of the watershed the area as a whole is well drained. Excepting those which drain the Ouachita, Wichita, and Arbuckle Mountains, tributaries in ordinary times do not flow swiftly. The lower reaches of the Red River-Ouachita Basin contain many old channels, bayous, lakes, and swamp areas where the stream currents are sluggish and the channels winding and tortuous. Stream beds are largely of sand or silt, especially those of the larger tributaries; but in the mountainous regions and also in some parts of the plains and prairies of Oklahoma and Texas most stream beds are very rocky. The largest continuous area of mountain land in the Red River-Ouachita Basin occurs in the northeast portion. This region is part of the Southern Ozarks known as the Ouachita Mountains, which within this basin comprises a territory approximately 200 miles long in an east and west direction and averaging 40 miles in width. Here the elevations range from 500 feet above sea level along the southern border of the mountains to nearly 2,000 feet on the highest peaks and ridges. The general trend of the ridges is east and west. Slopes are steep throughout and usually contain considerable broken rock exposed in the surface soil. This mountain

area presents the best and possibly the only opportunity in the entire basin for the storage of surplus storm waters, through building dams across the valleys.

West of the Ouachita Mountains in southern Oklahoma are two comparatively small mountain ranges, the Arbuckle and Wichita Mountains. The Arbuckle Mountains in south central Oklahoma vary in elevation from 750 to 1,350 feet above sea level with the highest areas in the western part. The Wichita Mountains lie still farther to the west, in southwestern Oklahoma and reach an elevation of 2,000 feet. This range is more rugged than the Arbuckle Mountains.

The region adjacent to these rougher areas of land consist of the rolling plains and prairies of Texas and Oklahoma and the interior coastal-plain region of Arkansas, Louisiana, and northeast Texas. The greatest part of the drainage basin lies within this rolling phase. The flat lands are of two types: (1) The alluvial bottom lands of the Red and Ouachita Rivers and their major tributaries, limited mostly to the eastern and southern parts of the watershed, and largely below an elevation of 100 feet; (2) the high plains or staked plains of the western Texas panhandle. These plains lie between 4,000 and 5,000 feet above sea level. Adjacent to and intruding upon them from the east lies an irregular, rough, severely eroded country known as the Breaks. This district consists of tongues of bad lands extending back along the somewhat intermittently flowing headwater streams of the Red River.

A small part of the watershed has been classified as hills; this lies entirely in northwestern Louisiana.

Following is a table showing the division of the watershed by various topographic types, the area which falls into each, and the per cent which each makes of the total:

Tributary	Mountains		Hills		Rolling		Flat		Breaks		Total
	Area	Per cent	Area	Per cent	Area	Per cent	Area	Per cent	Area	Per cent	
	Square miles		*Square miles*		*Square miles*		*Square miles*		*Square miles*		
Ouachita	3, 356	18	186	1	8, 389	45	6, 712	36	----------	------	18, 643
Red	5, 564	8	2, 086	3	43, 815	63	13, 910	20	4, 173	6	69, 548
Total	8, 920	10	2, 272	3	52, 204	59	20, 622	23	4, 173	5	88, 191

Geology and soils.—There are four major geological formations in the Red River-Ouachita Basin, namely: (1) The mountains, (2) Great Plains, (3) Coastal Plains, and (4) the alluvial plains of the river bottoms.

The mountains are in three distinct groups, the largest of which is the Ouachita Range, occupying approximately 7,980 square miles of the northeast part of the watershed. Sandstone, shale, and limestone are the principal rock formations present. The sandstone, due to its hardness and resistance to weathering, forms the ridges, and the softer rocks, having eroded more rapidly, form the valleys. Hanceville loams are the principal soils derived from these rocks. The stony phase of this soil is the one most susceptible to erosion.

However, this susceptibility is due largely to the fact that the stony loam is found commonly on the steeper slopes, where the topography more than the texture of the soil is the cause of washing.

West of the Ouachita Mountains and in the Great Plains lie the Arbuckle and Wichita Ranges. The former region is quite similar to the Ouachita in geology, except that hard limestones form the ridges. Much of the soil is gravelly and stony, and considerable erosion takes place on those slopes where the protective vegetative cover has been removed. The Wichita Mountains are mostly composed of granites, except for a few outlying ranges where limestone predominates.

Although erosion in the Wichita Range is not as serious as in the mountains farther east, the topography is so rough that rapid run-off and erosion can not fail to follow removal of protective vegetation.

The Great Plains form a large region lying to the west of the east cross timbers and Ouachita Mountains regions. The underlying formations consist of limestone, sandstone, shale, wind-blown material, and water-transported deposits washed from the igneous formations of the Rocky Mountains. The high plains of the Texas panhandle consist of silt and clay soils of this latter formation. Farther east the soils are more nearly residual, formed from the underlying sandstone, shale, and limestone farther north which have been washed down by shifting streams. Still farther east in the west cross timbers, Edwards Plateau, and eastern prairie regions the soils are residual, having been formed by the weathering of the underlying rock. Loams, clays, and clay loams predominate.

The texture of these soils is such that washing would be a serious problem were it not for the lack of topographic relief. The one exception to this lack of rugged topography in the Great Plains is found in the Texas panhandle. A steep escarpment separates the high plains from the lower plains farther east, a total rise of 1,000 feet in elevation taking place within a distance of a few miles. The steepness of some of the slopes in this region, especially along drainage lines, has caused severe erosion. This washing has continued until large, irregular areas, mainly along the water courses, have been so dissected that they are unfit for use other than grazing. This region is known as the Breaks.

The coastal plain is similar to the Great Plains in that much of the soil was formed by the action of water. This occurred when the region now known as the coastal plain formed part of the sea. At that time soils washed down from the uplands farther north were emptied into the ocean. The finest soil particles were held longest in suspension, and therefore were carried farthest out or deposited in the deep, quiet waters nearer shore. Due to the fineness of the soil particles and to stiff clay subsoils present in many places erosion is a serious problem in parts of the coastal plain. This is especially true where the topography is rough.

Two of these areas occur in the Red River-Ouachita Basin. One is located in northwestern Louisiana, the other in northeastern Texas. A third area in this region, critical from the standpoint of soil erosion, is one located just west of the Red River in northwestern Louisiana. However, it is rough topography rather than soil which is the prime cause of soil washing here.

The alluvial plains of the river bottoms comprise but a small amount of the total area of this watershed. Soils have been deposited by the rivers themselves and consist mostly of silts or clays. The texture of these soils is such that they would be subject to severe erosion if they had occurred on slopes. Due to this lack of topographic relief erosion on these lands is negligible.

Climate.—The mean annual precipitation varies from 20 inches at the source of the Red River to 55 inches at its mouth and averages about 39 inches for the Red and Ouachita watersheds together. Slightly more than half of the rain occurs during the warm half of the year. Spring precipitation during March, April, and May normally varies from about 5 inches at the source of the Red River to 15 at its mouth, and 16 inches over much of the Ouachita Basin. In 1927 as much as this fell during the shorter period of March and April.

Normal annual temperatures vary from 59° F. at the source of the Red River to 68° at its mouth. Similarly the normals for January range from 30° to 50°, and for July from 75° to above 80°. The average normals are about 64° for the year, 42° for January, and 79° for July. The average number of days with snow cover varies from less than 7 to 15 and averages about 8 days per year. Evaporation from a free water surface varies from 46 to 53 inches per year according to determinations made by the Office of Biophysical Investigations, United States Department of Agriculture, for periods of 5 to 11 years, at three points along the western part of the Red River valley. This may be contrasted with the evaporation of 32 inches per year at Crowley, La. As pointed out by Kincer,[1] the heavy evaporation in western Texas makes 30 inches of precipitation there equivalent to no more than 20 inches in eastern North Dakota. The 20-inch line of average annual precipitation roughly follows the one hundredth meridian of west longitude. This line in North Dakota passes through a region where wheat, oats, and similar crops are grown, whereas in Texas it passes through grazing country where only drought-resistant crops are grown.

Historical development.—Agriculture and lumbering are the leading occupations in the eastern portion of the Red River-Ouachita Basin, including all of the Ouachita drainage. In the central portion of the basin lumbering is less important, and in the western part it does not exist.

Climate and topography determine the distribution of the forest associations, which consist of bottom-land hardwoods over a considerable area near the mouth of the Red River, in a narrow belt along the east side of the Ouachita drainage, and along the Ouachita and its tributaries into south-central Arkansas and up the Red and its tributaries into Texas and Oklahoma. The remainder of the Ouachita drainage, together with that of the Red as far west as Atoka County, Okla., and Upshur County, Tex., is in pine. West of the pine and the bottom-land hardwoods regions in Texas and Oklahoma, the uplands and river bottoms support a growth of oaks, hickories, and other upland hardwoods; these become more scrubby and more interspersed with areas of grass farther to the west, until only occasional mesquite and shin oak above, and plum and willow

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[1] Atlas of American Agriculture, Part II. Climate, 1922. "Evaporation," by J. C. Kincer.

along the streams vary the great stretches of grass so characteristic of the high plains. The grass associations fall into three groups: Tall grass, desert savanna, and short grass, the last two of which mark a region having a permanently dry subsoil.

Agriculture and lumbering have somewhat modified the original cover, but because of differences in political history similar regions have not always undergone similar modification. The portion of the basin lying in central Louisiana was settled by the French in the eighteenth century, but settlement in northern Louisiana and Arkansas did not take place till after the Louisiana Purchase in 1803, and was not rapid until 1830 or 1840. In the meantime the boundary treaty of 1819 excluded from the possession of the United States that part of the basin lying in Texas. Some settlement took place along the Red River in Texas, however, and at points south, and in 1845 the "Republic of Texas" was annexed by the Government and became a State. All public land in Texas remained the property of the State, and agricultural development, including clearing of much forest land, was rapid east of the Red prairies and high plains. Across the Red River, in Oklahoma, the land was withheld from settlement until 1889–1892, when the public domain was opened to homestead and there ensued a great rush of farmers eager to take up the naturally open land. The result of this varied history is apparent to-day in the high state of cultivation of northeast Texas and central Oklahoma and the wilderness conditions in the adjacent portions of southeast Oklahoma.

Two decades before Oklahoma was opened to homesteaders cattle ranching became established on the red prairies of Texas, and about 1880 invaded the high plains. At first, stock was supported entirely on open range, but in the later eighties sorghum was raised for winter feed. The first railroad crossed the panhandle in 1887, and this stimulated the division of large ranches into farms. From that time on, increasing areas have been cultivated, Herefords have replaced the longhorns of the original ranches, and the cattle business has become more and more dependent upon growing winter feed. The division of the region into farms has decreased grass fires.

The final stage in the development of the basin has been the extensive lumbering in Louisiana and Arkansas. This began about 1890 and since 1900 has assumed gigantic proportions in both pine and bottom-land hardwoods. Until very recently annual fires have preceded and followed the saws, leaving thousands of square miles of country with a productive capacity and a protective cover far below their maximum.

In Texas and in western and central Oklahoma the bulk of the land is in farms. In Louisiana, Arkansas, and the pine region of eastern Oklahoma lumber companies and State or Federal Governments own about the same amount of land as do farmers. Louisiana has a State forest of nearly 6,000 acres near Alexandria, on the Red River drainage, and there are national forests in Arkansas (the Ouachita, on both Ouachita and Red River drainages) and in Oklahoma (the Wichita, entirely within the drainage of the Red).

Except in the westernmost part of the basin there are no stock laws, or if they exist they are not enforced. Cattle graze on open range, and because the custom of the country is to burn over the range annually farmers and stockmen have been responsible for much

of the burning which has occurred both in the forest and on cut-over land.

The present amounts of forested, unimproved, and improved land, by types, drainages, and other subdivisions, are given in the accompanying table (I). For the purpose of bringing out certain local differences the Little River drainage in Louisiana, constituting that portion of the Red River drainage next to the Ouachita drainage, has been considered separately. Its location is shown on the accompanying maps. The ratings assigned to forested, unimproved, and improved land, by the same subdivisions as those mentioned above, are also given in an accompanying table (II).

CONDITION OF LAND OTHER THAN FOREST

Throughout that portion of the basin east of the Red Prairie region, corn and cotton are the principal crops; sugar-cane is important in the lowlands of Louisiana. In the more aird western portion sorghum and similar plants are grown for forage and grain. All these crops except cane leave the soil more or less exposed to washing, because they are open grown and intertilled. In the river bottoms within the boundaries of the bottom-land hardwood type farther east, this exposure is of little importance, and the protective value of the soil is rated high because the tillage increases absorptive capacity. On the rolling and hilly land within the boundaries of the upland hardwood and the pine types, within the region of moderate to heavy precipitation or of the cloud bursts characteristic of the plains, the cultivation of these crops will result in serious erosion unless contour plowing or terracing is practiced. Contouring is common throughout the region, especially in the steeper country in Arkansas; terracing is too little used, and the cultivated land within the boundaries of the upland types is accordingly rated down. There is evidently need throughout the basin for improvement in agricultural practices.

The unimproved land in the basin varies from the fresh-water swamps and the grass and brush covered cutover land of the bottomland hardwoods region in Louisiana to the naked slopes of the breaks and the level land covered by the native short grass vegetation of the high plains. It contains only moderate amounts of abandoned cultivated land, and these are concentrated principally in the hilly regions of southwest Arkansas and northeast Texas. Throughout the basin the unimproved lands are grazed, and throughout the portion east of the red prairies they are burned frequently. In the pine region fires often occur annually. The wetter bottoms, with their characteristic growth of hardwood, suffer fewer fires than do the uplands and therefore are given a higher protective rating. The most important unimproved lands from the standpoint of erosion and flood control are those in the pine and upland hardwood types each of central Texas and Oklahoma, and those in the breaks of Texas. The former, especially those within the boundaries of the pine type, should be in forest, or should be so managed that their present grass covering would be very much improved. It is significant that practically every county agricultural agent within the boundaries of the pine and upland hardwood types states (in answer to a questionnaire submitted in August, 1927) that the planting of land not needed for agriculture in his county would materially decrease run-off and

erosion. In the breaks country, however, opinion is divided, and the complexity of the erosion problem in that locality, combined with the dry climate, indicates the need of research before making definite recommendations.

CONDITION OF FORESTS

The general distribution of the three forest associations existing in the Red River-Ouachita Basin is described above in connection with the historical development of the region, and the location of the type boundaries are indicated on the accompanying map.

The southern portion of the pine type in Louisiana consists of practically pure long leaf, much of which until very recently has been subjected to annual burning. Here the stand is open, the scanty litter characteristic of southern forests has been destroyed, and con-

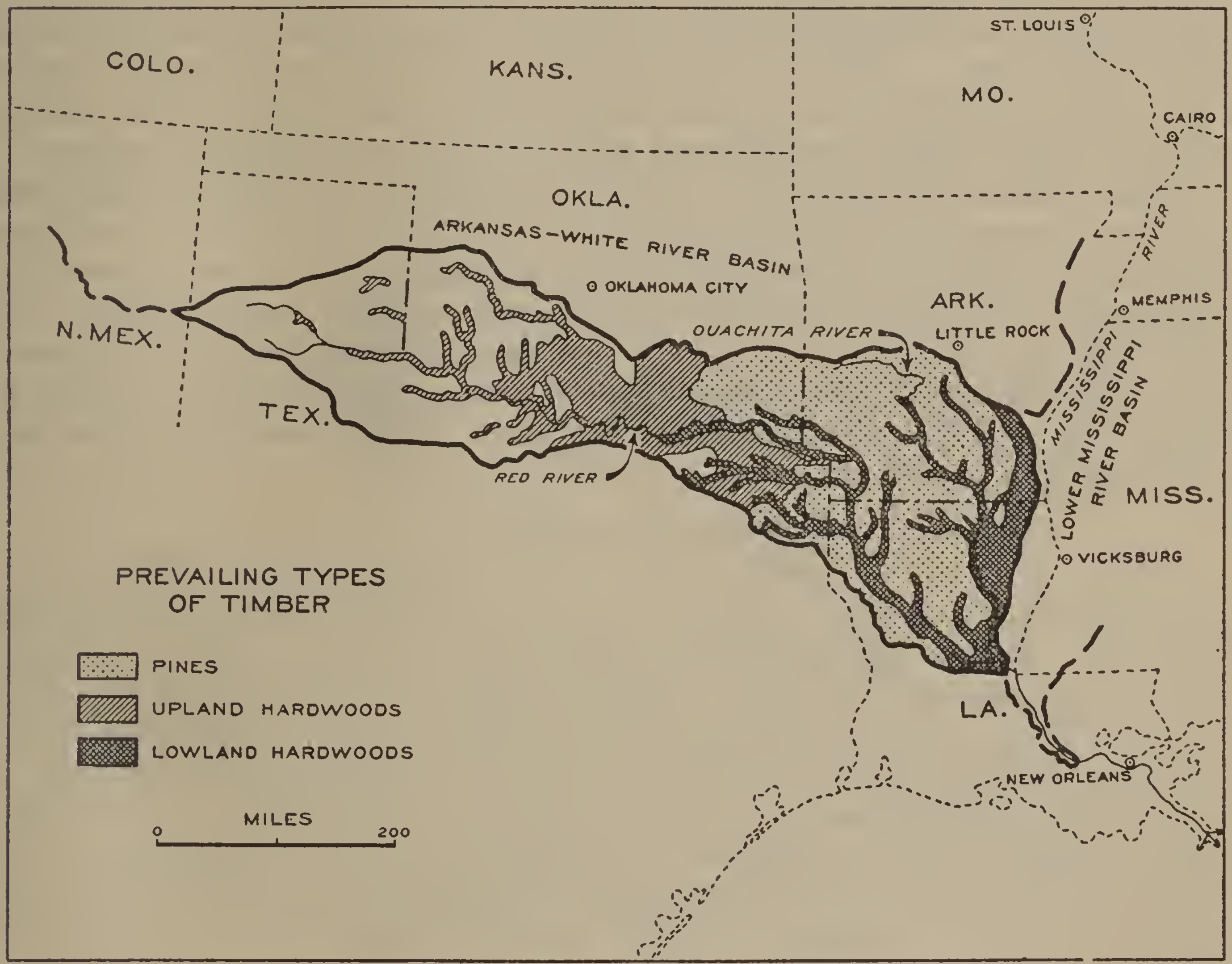

FIGURE 1.—Red River-Ouachita Basin

sequently the protective rating is low. Farther north in Louisiana, and in Arkansas and Texas, shortleaf and loblolly pine replace the long leaf, the forest contains more or less hardwood in mixture with the pines, brush and reproduction occupy more of the ground, and there is often from half an inch to an inch of litter. Fires have been less frequent in these sections, occurring periodically rather than annually. Notwithstanding the protection policy of the Ouachita National Forest in Arkansas and the work of a few progressive lumber companies in Arkansas and Louisiana, fires are of common occurrence. The breaking up of forest areas by agricultural land in Texas decreases the fire hazard there. In Oklahoma the pine forest is of poorer quality than in the other States, and fires have been more serious than in the adjoining shortleaf forests of Texas and Arkansas.

The bottom-land hardwoods type consists of red and tupelo gums, cypress, and a great variety of oaks and other hardwood species. Toward the west the cypress becomes less and less important and the oaks predominate over the gums, until finally the type merges with the upland hardwoods. The bottom-lands forests are in good condition, little damaged by fire, with dense undergrowth and often with one to two inches of litter on unburned areas. Their protective value is high, but they are relatively unimportant in this study because of their occurrence on limited and level areas.

The upland hardwoods type is actually a series of transition types between the shortleaf pine and hardwoods described above and the grass of the western plains. Where it is adjacent to the pine type proper it consists of magnificent stands of oaks and hickories, with a sprinkling of other hardwoods and a little pine. To the west many species drop out entirely, those remaining are increasingly scrubby, and the stands are more and more broken up by grassy areas. West of the West Cross Timbers, stands consist almost exclusively of mesquite and scrub or shin oak on the plains, and of willow, cottonwood, and plum in the watercourses below.

Fires reduce the protective effect of the better forests to the east, but the decrease of prairie fires in the western part of the drainage, combined with intensive grazing, has within recent years caused a significant extension of wooded and bushy areas in many places. As a whole, the upland hardwoods are rated rather low, though still beneficial, in their protective influence, and their condition could be improved and their area extended with direct benefit to the soil conservation program.

CRITICAL AREAS

There are a number of areas within the boundaries of the Red River-Ouachita Major Basin, which have an important influence on stream flow and erosion. These include (1) the breaks in northwestern Texas and southwestern Oklahoma; (2) the Wichita Mountains in southwestern Oklahoma; (3) the Arbuckle Mountains in south central Oklahoma; (4) the Ouachita Mountains in southwestern Arkansas and southeastern Oklahoma; (5) a portion of the agricultural district in northeastern Texas; and (6) the hilly country in northern Louisiana which lies north and south of the Red River.

Erosion is responsible for the formation known as the breaks, an intricate maze of steep slopes bordering the streams which cut back into the high plains from the red-prairie region and extend out along some of the water courses in the red prairies as well. Little is being done to check this erosion which is being aggravated in some places by overgrazing. Remedies await a more definite knowledge of the conditions and a determination, through research, of the methods necessary for their improvement. In the meantime this region has an extremely detrimental influence in its effect on the floods of the Mississippi River Basin.

The Wichita and Arbuckle Mountains in southern Oklahoma are two relatively small areas, widely separated from any other mountainous country, which because of their rugged topography are

susceptible to serious erosion whenever the ground cover is disturbed. The former is largely under Federal administration in the Wichita National Forest, but the latter is not subject to any Government regulation. If care is taken to employ those agricultural methods best suited to the prevention of soil wash; if fire protection is given, and overgrazing prohibited, no detrimental influence as regards soil erosion on these areas should result. Under present conditions, the Wichita-Mountain region is classed as beneficial and the Arbuckle Mountain as detrimental in their influence on erosion and run-off.

The Ouachita Mountains mark the most extensive area of rough topography to be found in the watershed. As long as a protective cover of timber, brush, or grass is kept on these steep slopes there will be little danger of excessive run-off and erosion. This will

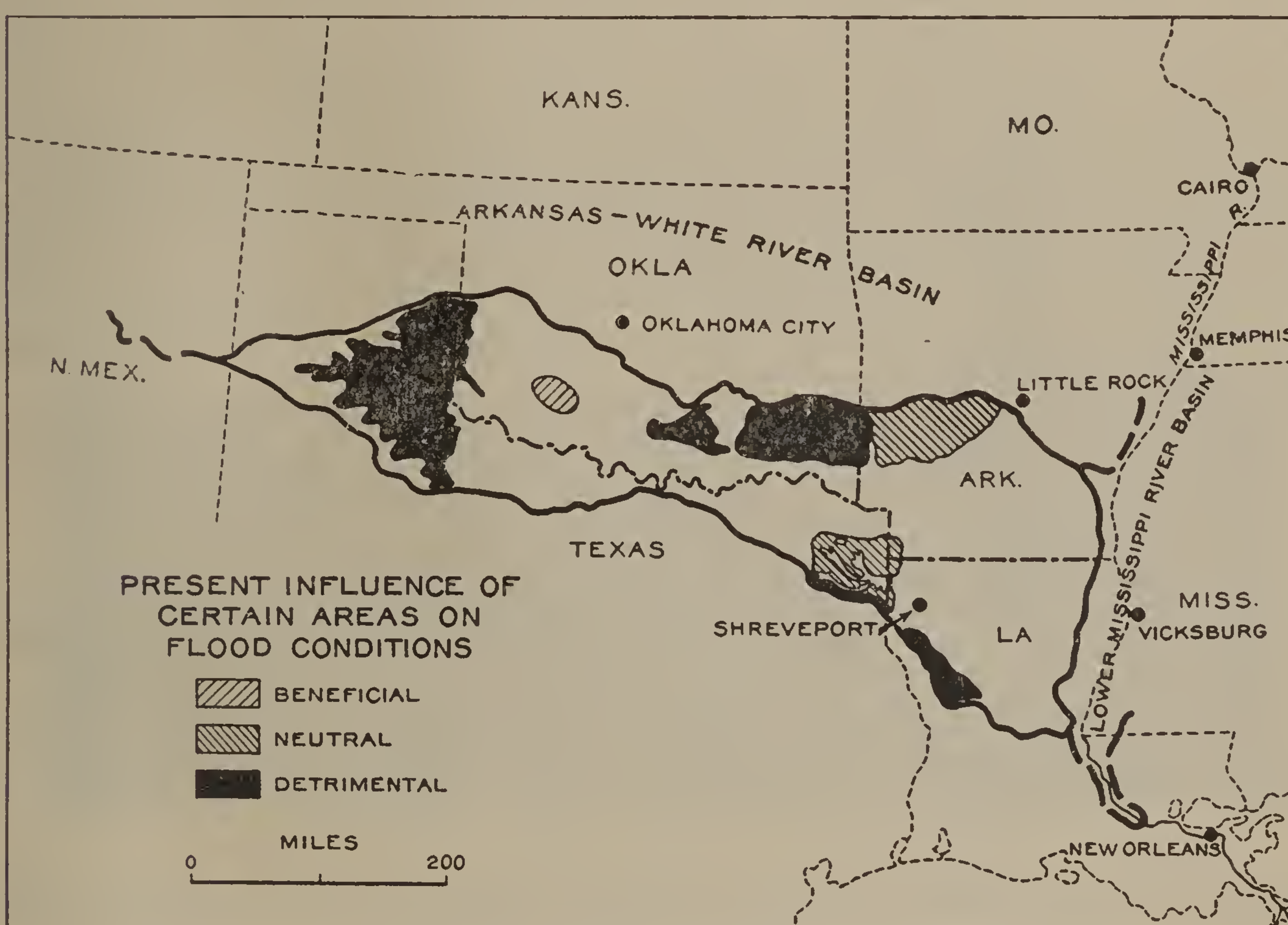

FIGURE 2.—Red River-Ouachita Basin

entail methods of logging whereby a stand of trees is kept continuously on the land through selective logging, an adequate system of fire prevention, and, on cultivated lands, the employment of agricultural practices best suited to the prevention of erosion. Some headway has already been made in fire protection and selective cuttings on the Ouachita National Forest and by a few of the progressive lumber companies controlling extensive holdings in this region, by leaving a vegetative cover on the ground at all times (by diameter limit cuttings) and by instituting fire-control measures. These measures have not gone far enough to make this region of beneficial influence in its effect on flood control, and it has been classed as detrimental except for a portion in Arkansas, including the Ouachita National Forest and adjoining areas which have been classed as of neutral influence.

Parts of the rich agricultural region of northeastern Texas have suffered from erosion on those soils which are particularly susceptible to washing if preventative measures are not taken. The solution is to keep the steeper slopes in timber, to guard against the use of wasteful methods of tilling the soil, and to prevent fires. At present the influence of this region is neutral.

The hilly country of northern Louisiana, generally better suited to forestry than to agriculture, has suffered severe losses in its producing capacity through clear cutting of the virgin stands of pine, and until recently by receiving practically no protection from annually recurring fires. This land should be kept in forest cover, and fire protection is absolutely essential for that. Some planting of denuded areas will be necessary, but the natural reforestation of much of this region will follow after fire protection is obtained.

The relative protective value of the watershed has been rated according to the influence of the factors of soil, physiography, precipitation, and general character of cover (including forest cover) on erosion and run-off. This gives an indication of the relative importance of this watershed in respect to flood control when compared with other drainages. Separate ratings for each cover type and by kind of land used have been made and averaged by minor drainages and for the major basin as a whole. Forest cover ratings appear in an accompanying table (II), but a brief summary of all the ratings for each watershed is as follows:

Drainage	Area in square miles	Ratings [1]					Forest cover rating			
		Soil	Physiography	Precipitation	Character of cover	Total	Pine	Bottom-land hardwoods	Upland hardwoods	All types
Ouachita	18,643	76	73	58	78	71	80	95		83
Red	69,548	75	66	74	75	72	76	98	80	79
Total	88,191	75	67	71	76	72				[2] 81

[1] Character of cover includes not only forest cover, shown separately in this table, but also improved and unimproved lands.
[2] Average.

The designation of certain areas as critical and the detailed recommendation of certain forestry measures to be applied on them and elsewhere, must not obscure the fact that excessive run-off and erosion occur also in other places and can be prevented by other than forestry measures. Minor losses on cultivated land throughout the basin are, in the aggregate, probably far greater than on the worst of the critical areas designated in this report. Except in the eastern bottom lands and in the areas of deficient rainfall in the western end of the drainage, the erosion of roadside ditches is in its entirety another problem of staggering proportions. It is the cumulative effect of many small contributions of silt or water which makes these problems important. Fortunately they can be handled in the same way, piecemeal, by the cumulative effect of many small corrections, such as sodding ditch banks, increasing the organic matter in plowed fields, planting waste land to grass or trees, and covering cuts and

FIGURE 3.—Pure longleaf pine land on upper coastal plain soil. Devastated by Buchanan Lumber Co., Red River drainage. Near White Surphur Springs, below Jena, La.

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FIGURE 4.—Cut-over longleaf land 5 miles south of Cypress, La. Red River drainage

FIGURE 5.—Ten-inch cottonwood buried by 6 feet of silt from Red River during 1927 flood. New roots have developed near surface of deposit. Rapids Parish, La. Outside levee. Bottom-land hardwoods. Red River drainage

fills with honeysuckle or other vegetation. The solution of these problems is essential to the completion of any program of flood control, and all available agencies must cooperate in the work.

SUMMARY

Because of the importance of the Red River-Ouachita drainage area from a flood standpoint, no less than from one of erosion, it is necessary that a complete and continuous forest cover should be maintained and developed. Not only is it necessary that a forest cover be maintained at all times, but it is imperative that the management of forest lands in this region take strictly into account the effect that these lands have upon the situation in the Mississippi Basin. Proper forest management, therefore, is essential.

Particularly is proper forest management necessary in the Ouachita Mountains where most slopes are unsuited for cultivation. The effect of clearing or clean cutting is shown on many of the slopes in erosion that has resulted. Clear cutting therefore should be avoided wherever possible and a system of cutting used which will permit a continuous cover upon the area at all times. With protection and with careful cutting methods, regeneration of the prevailing forests should be comparatively easy. Without an adequate fire protection this will be difficult or impossible, even with any system of management. Because removal of all or a major portion of the timber on the slopes at one time will result in a serious loss of soil and a reduction in the protective value of the cover against rapid run-off, it is evident that some system of selective logging must be used. Under such a system only that portion of the merchantable timber, such as for example the trees above a certain diameter class or trees possessing certain characteristics, would be removed. This would provide for the quick reestablishment of a forest and maintain all forest litter in as productive a state as is possible.

Proper forestry methods, however, should result in adequate yield and income from the forest cover and at the same time maintain to the utmost the advantage of full soil protection. Throughout this drainage, methods of harvesting the timber crops should be adapted to the individual situation. Any logging methods used should so be adapted to the conditions that they would bring about the least possible disturbance to the soil and to the forest cover. In this way the maximum protection to the soil would be assured.

As indicated, full protection from forest fires is necessary. Not alone is it necessary to guard against the fires which commonly follow logging operations, but it is also necessary to guard against the customary "light burning" or "woods burning" practice which is prevalent in the region. Largely through ignorance of the damage that fires do, local residents are accustomed to setting fire to the forests for a variety of reasons, believing that thereby they benefit grazing, remove obnoxious insects or animals, or make progress through the woods relatively easy. Thousands of acres are thus wantonly burned each year with little or no justification for the practice. The result of these fires is detrimental to the best interests of the lower Mississippi in that the removal of the litter paves the

way for rapid run-off and for a decreased water absorption by the soil.

A considerable portion of this region lies in Arkansas, in which State there is not now any State forestry agency looking to the control and suppression or even the reporting of fires. The State should establish such an agency as soon as possible. This would then permit the extension of privileges of section 2 of the Clarke-McNary Act to Arkansas, thereby providing for Federal participation in the local protection of forests from fire. The full amount as authorized by the Clarke-McNary law should be used in this activity.

Other States should be encouraged to increase their protective forces to meet local situations, and the Federal Government should extend its aid financially.

Although for the most part natural regeneration of forests is a comparatively simple process in this region, still there are considerable areas where forest planting is needed. Planting here is not the difficult task that it is in some regions, so that success should crown any efforts made. The acreage involved and the need for remedial action on an important watershed makes necessary the prompt beginning of reforestation activities. On many of the abandoned farm lands and on some of the badly eroded cut-over areas planting will be necessary to prevent erosion and to reduce extensive superficial run-off. State cooperation with the Federal Government under the provisions of the Clarke-McNary law would aid in establishing a cover on many areas where planting is necessary. Planting is also necessary on an extensive scale by the State, the Federal Government, and private forest landowners. The influence of forests upon run-off and erosion is so great that a forest cover should be established as quickly as possible in all denuded areas. At present planting is carried on on such a small scale that progress is almost negligible. Encouragement, example, and funds are needed that the work may proceed more rapidly.

As in many other regions, improved agricultural methods in such farm sections as the northeastern part of Texas, can do much to reduce the amount of soil eroded annually. While planting of forests may not be advisable or possible on much of this land, many waste areas can be revegetated with some form of cover that would prevent erosion and increase thereby the amount of water absorbed into the soil at times of heavy precipitation.

Additional extension activities on a cooperative basis between the States and the Federal Government is necessary in order that the owners of forest lands may be reached and made to understand that they can do much toward the reduction of the flood flows in the Mississippi through the proper forest management.

Much of the forest area in the critical areas should be in public ownership particularly on lands in the higher elevations. This would include the extension of national forest areas in the Ouachita Mountains. Public forests should also be established in the Arbuckle Mountains of Oklahoma.

On account of the lack of knowledge of how best to handle forest lands, from a flood and erosion standpoint, there is need for many phases of forestry research. Best methods of cutting timber in order to provide for the maximum protection of slopes and to insure

adequate regeneration are not yet known. A study of the proper technique of forest planting of many of the eroded areas is necessary that a suitable and sufficient cover may be established in the shortest possible time. In some sections, as in the "breaks" region, the proper grazing management must be determined to bring about proper land use and so to reduce erosion. On some of these areas it will be necessary also to bring about the establishment of a vegetative cover. For this it is necessary to know the best plants to be used and the proper methods for their planting.

Research is also necessary on many areas in order to determine what methods of forest engineering would materially control erosion at the smallest possible expense. Although some data are available from other regions, these can be applied only by analogy and may not be adapted to the particular soils and climatic types of this section. As the problem of restraining flood flows and of controlling silt is of such magnitude and undoubtedly there will be large expenditures of money before such measures can be fully put into effect, it is necessary to know at the earliest practicable date how best to handle these lands. Research, therefore, becomes an exceedingly vital part of the whole program. Part of this is provided for in the McSweeney-McNary Forest Research Act but this has not contemplated for this region, except in part, work of the scope and magnitude necessary for flood-control purposes.

At the present time forests are probably only a third fully productive. By measure of forest practices, by proper handling of lands, and by protection, the forests of this region could be made to play and should so play a vital part in the control and handling of floods in the Mississippi River.

TABLE I.—*Area in each cover type by drainages*

Drainage, Red River and Ouachita Basin	Pine association									Bottom-land hardwood association								
	Forest		Unimproved		Improved		Total		Per cent of total drainage area in association	Forest		Unimproved		Improved		Total		Per cent of total drainage area in association
	Square miles	Per cent	Square miles	Per cent	Square miles	Per cent	Square miles	Per cent		Square miles	Per cent	Square miles	Per cent	Square miles	Per cent	Square miles	Per cent	
72. Ouachita, La.	612	24	1, 455	57	485	19	2, 552	100	49. 7	1, 136	44	981	38	465	18	2, 582	100	50. 3
72. Ouachita, Ark.	8, 173	67	2, 196	18	1, 830	15	12, 199	100	90. 3	786	60	275	21	249	19	1, 310	100	9. 7
72. Total	8, 785	59	3, 651	25	2, 315	16	14, 751	100	79. 1	1, 922	50	1, 256	32	714	18	3, 892	100	20. 9
73. (*a*) Red River (exclusive of Little River), La.	1, 398	28	2, 646	53	949	19	4, 993	100	----------	601	28	1, 072	50	472	22	2, 145	100	----------
73. (*a*) Red River (exclusive of Little River), Ark.	2, 476	59	671	16	1, 049	25	4, 196	100	----------									
73. (*a*) Red River (exclusive of Little River), Tex.	984	32	1, 168	38	923	30	3, 075	100	----------	523	50	220	21	304	29	1, 047	100	----------
73. (*a*) Red River (exclusive of Little River), Okla.	2, 968	70	806	19	466	11	4, 240	100	----------									
73. (*a*) Red River (exclusive of Little River), N. Mex.	-------	------	-------	------	-------	------	-------	------	----------	-------	------	-------	------	-------	------	-------	------	----------
73. (*a*) Total	7, 826	47	5, 291	32	3, 387	21	16, 504	100	24. 8	1, 124	35	1, 292	41	776	24	3, 192	100	4. 8
73. (*b*) Little River, La.	671	26	1, 702	66	206	8	2, 579	100	85. 0	196	43	127	28	132	29	455	100	15. 0
73. Complete	8, 497	44	6, 993	37	3, 593	19	19, 083	100	27. 4	1, 320	36	1, 419	39	908	25	3, 647	100	5. 3
Total for Red River and Ouachita Basin	17, 282	51	10, 644	31	5, 908	18	33, 834	100	38. 4	3, 242	43	2, 675	35	1, 622	22	7, 539	100	8. 5

TABLE I.—*Area in each cover type by drainages*—Continued

Drainage, Red River and Ouachita Basin	Upland hardwood association									Total of all associations								
	Forest		Unimproved		Improved		Total		Per cent of total drainage area in association	Forest		Unimproved		Improved		Total		Per cent of total drainage area in association
	Square miles	Per cent	Square miles	Per cent	Square miles	Per cent	Square miles	Per cent		Square miles	Per cent	Square miles	Per cent	Square miles	Per cent	Square miles	Per cent	
72. Ouachita, La.										1,748	34	2,436	47	950	19	5,134	100	100
72. Ouachita, Ark.										8,959	66	2,471	18	2,079	16	13,509	100	100
72. Total										10,707	58	4,907	26	3,029	16	18,643	100	100
73. (*a*) Red River (exclusive of Little River), La.																		
73. (*a*) Red River (exclusive of Little River), Ark.																		
			TALL GRASS															
73. (*a*) Red River (exclusive of Little River), Tex.	5,412	19	11,393	40	11,678	41	28,483	100										
			DESERT SAVANNAH															
73. (*a*) Red River (exclusive of Little River), Okla.	207	3	4,967	72	1,724	25	6,898	100										
			SHORT GRASS															
73. (*a*) Red River (exclusive of Little River), N. Mex.	229	2	8,578	75	2,630	23	11,437	100										
73. (*a*) Total	5,848	13	24,938	53	16,032	34	46,818	100	70.4	14,798	22	31,521	48	20,195	30	66,514	100	100
73. (*b*) Little River, La.										867	29	1,829	60	338	11	3,034	100	100
73. Complete	5,848	13	24,938	53	16,032	34	46,818	100	67.3	15,665	23	33,350	48	20,533	29	69,548	100	100
Total for Red River and Ouachita Basin	5,848	13	24,938	53	16,032	34	46,818	100	53.1	26,372	30	38,257	43	23,562	27	88,191	100	100

TABLE II.—*Cover ratings, Red River—Ouachita Basin*

Drainage area and State		Pine				Bottom-land hardwoods				Upland hardwoods				Total all types			
		Forest	Unimproved	Improved	Total cover	Forest	Unimproved	Improved	Total cover	Forest	Unimproved	Improved	Total cover	Forest	Unimproved	Improved	Total cover
72. Ouachita	La	75	55	75	64	95	75	90	86								
	Ark	80	65	80	77	95	80	95	92								
72. Total		80	61	79	75	95	76	92	88					83	65	82	78
73. (*a*) Red River (exclusive of Little River)	La	75	60	70	66	100	85	95	91								
	Ark	78	75	75	77												
											TALL GRASS						
	Tex	85	70	70	75	95	75	90	89	80	70	75	74				
											DESERT SAVANNAH						
	Okla	75	70	70	74					85	75	75	75				
											SHORT GRASS						
	N. Mex									85	85	75	83				
73. (*a*) Total														80	75	75	76
73. (*b*) Little River, La		75	55	65	61	100	75	95	92					81	56	77	65
73. Total		76	63	71	70	98	83	93	91	80	76	75	76	79	74	75	75
Total for Red River and Ouachita Basin														81	73	76	76

APPENDIXES

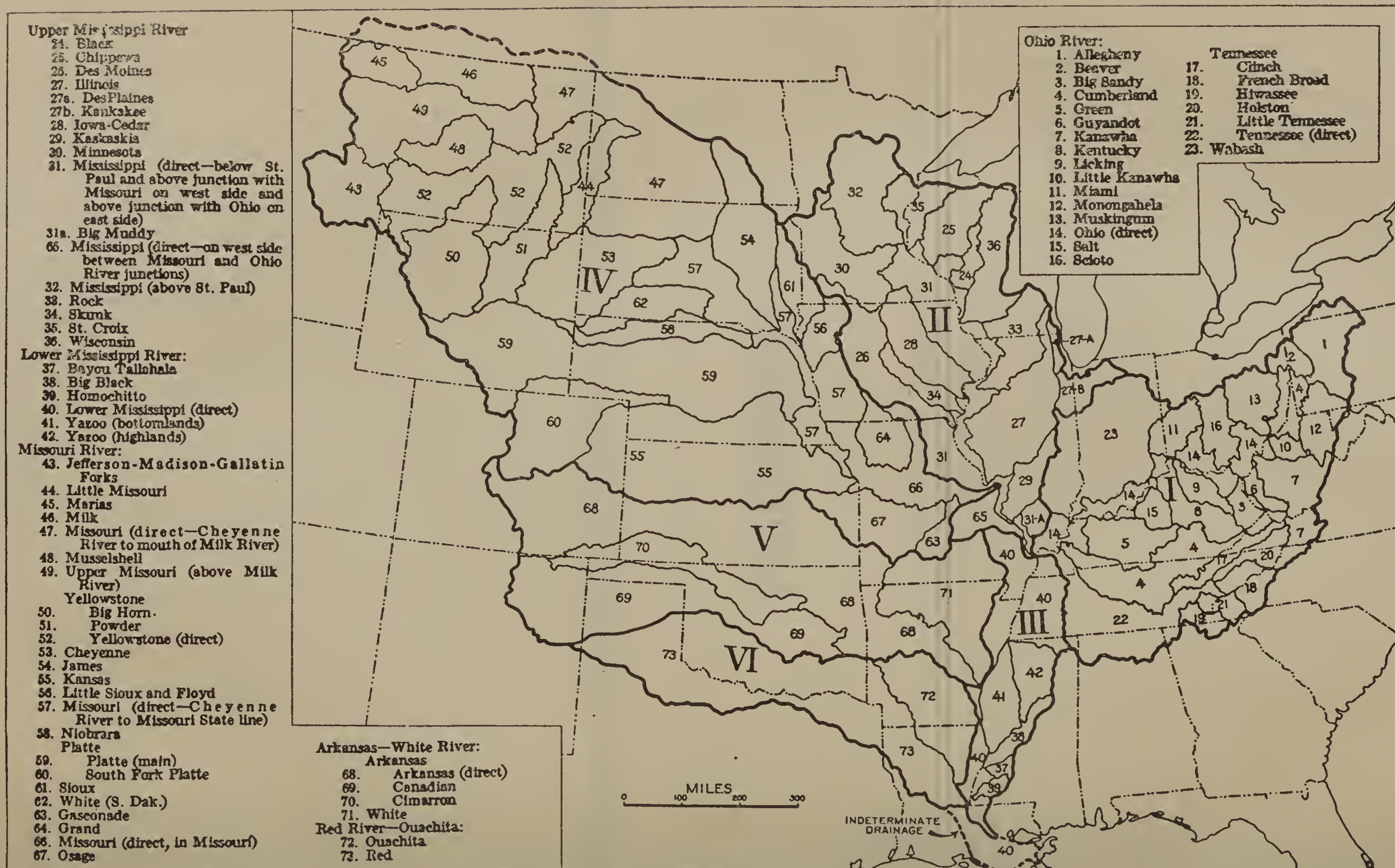

FIGURE 1.—Major and minor drainage basins

CONTENTS

The unit areas are treated in the following order:

APPENDIX I

DETAILED DISCUSSION OF INDIVIDUAL DRAINAGE BASINS

The data given for the individual drainage basins in the accompanying appendix have been prepared by a number of men in the Forest Service who have been engaged during the past year in collecting and bringing together the available information upon cover conditions in the minor drainage basins of the Mississippi. Credit for much of the work of the following is due to these men and the staffs of the various forest experiment stations and national forest districts, who have participated in this study. The credit for the preparation of these individual reports goes to the following men:

Basin	Unit drainage	Author
Ohio River	1–23	E. F. McCarthy, director Central States Forest Experiment Station.
Upper Mississippi River	24–36	Raphael Zon, director Lake States Forest Experiment Station.
Do	65	W. W. Ashe, senior inspector, eastern national forest district.
Lower Mississippi River	37–42	E. L. Demmon, director Southern Forest Experiment Station.
Missouri River	43–52	M. H. Wolff, assistant district forester, northern national forest district.
Do	53	H. D. Cochran, inspector Rocky Mountain National Forest district.
Do	54, 55, 57	P. Keplinger, inspector Rocky Mountain National Forest district.
Do	58, 59, 60	F. R. Johnson, chief of planting, Rocky Mountain National Forest district.
Do	61	Jay Higgins, supervisor, Nebraska National Forest.
Do	62	H. D. Cochran, inspector, Rocky Mountain National Forest district.
Do	63–67	W. W. Ashe, senior inspector, eastern national forest district.
Do	56	W. W. Ashe, senior inspector, eastern national forest district and F. R. Johnson, chief of planting, Rocky Mountain National Forest district.
Arkansas-White River	68–71	W. W. Ashe, senior inspector, eastern national forest district.
Red-Ouachita River	72–73	E. L. Demmon, director Southern Forest Experiment Station.

ALLEGHENY DRAINAGE AREA

(Area 1)

LOCATION

The source of the Ohio River is at the junction of the Allegheny and Monongahela Rivers; and the Allegheny, flowing from the north, is one of the more important tributaries. The basin of the

Allegheny lies partly in western Pennsylvania and partly in southwestern New York. The total area of the drainage is 11,683 square miles, 9,754 of which are in Pennsylvania and 1,929 in New York. The principal tributaries of the Allegheny are the Clarion and Kiskiminetas Rivers, and Red Bank, French, Brokenstraw, and Oil Creeks.

The drainage basin is about 185 miles long. In width it varies from 126 miles near the New York-Pennsylvania State line, to 47 miles at a point 25 miles above the mouth.

TOPOGRAPHY

The greater part of the Allegheny drainage lies in a much dissected plateau, part of the Allegheny plateau, and has at present the aspect of high rolling hills. The northwestern section of the watershed has been glaciated, so that the hills in this section are lower and more rounded and the valleys are less narrow and V-shaped. The southeastern part of the basin lies in the Allegheny Mountains, a region characterized by extensive ridges, the result of folding of the plateau. Only a small part of the drainage area confined to alluvial flats along the streams can be considered physiographically as "plains."

The approximate area in each of the four physiographical divisions of the basin is indicated in the following: Mountains, 9.4 per cent; hills, 75.3 per cent; rolling, 14.9 per cent; plains, 0.4 per cent.

The elevation at the head of the valley is slightly in excess of 2,200 feet, and at the mouth of the river, 703 feet. The greatest land elevation is in the southeastern portion of the valley in the main ridge of the Allegheny Mountains, where an elevation of 3,000 feet is reached. The western rim of the basin is lower, having a mean elevation of 1,330 feet. The mean elevation of the eastern rim is 2,275 feet. The slopes are steep, with the exception of those in the glaciated section.

The stream flows comparatively close to the western rim of the basin, leaving the greatest drainage area east of the main river, so that the eastern tributaries are much longer and much greater in number. This gives the valley in general a westerly exposure.

The streams in the northwestern, glaciated portion of the drainage are sluggish because they flow through buried valleys. The other tributaries to the main stream flow swiftly through narrow V-shaped valleys with short, steep grades and rocky beds. The upper reaches of the main stream are similar to the tributaries. The lower river from Pittsburgh north for about 50 miles has been slack watered by a series of six transportation dams.

Swamps are found in the glaciated section but not elsewhere. This is also true of lakes, of which there are about 15 in the drainage area. Chautauqua Lake in New York is the largest and Conneaut Lake in Pennsylvania is next in size. About 21 possible reservoir sites have already been surveyed on the main river and its tributaries. These combined would have a storage capacity of 49,725,-800,000 cubic feet.

GEOLOGY AND SOILS

The central portion of this basin, representing a much eroded plateau with stream drainage well established, lies within the Appalachian Plateau province. It is underlain by rock formations of the Pennsylvania system, the most prevalent summit and ridge formation being the Pottsville sandstone. The soil types are chiefly residual silt loams and sandy loams of the DeKalb series. They may sometimes be quite sandy and stony. Rock outcrops are common. The upland and ridge soil types are shallow with excessive drainage. They wash severely by sheet erosion when exposed or cultivated on slopes. The valley soil types are deeper, and under normal treatment do not suffer greatly from excessive erosion.

Within this basin ice is important in the carving of banks and subsequent bank caving along the main streams. Ice centers into all river management and engineering problems.

A considerable part of the plateau area is underlain with coal, oil, and gas of economic importance. These resources have determined the utilization of extensive land areas, and in such cases forest cover and soil quality have not been considered of major importance.

A belt along the northern border, including that portion of New York State within the basin, is underlain with limestone and shale of the Portage and Chemung groups of the Devonian period, and with sandstone and limestone of the Waverly groups of the Lower Mississippian. The northwestern portion, about 22 per cent of the basin, has been glaciated. The topography had achieved a considerable roughness before glaciation and the glaciation has resulted in the smoothing of the higher hills and the filling of the valleys with deep deposit. The drift mantle may be several hundred feet in depth. The soils have been derived from the weathering of the upper layer of this drift. They are classified as glacial shale and sandstone soils. (Volusia series.) The commonest soil type is a silt loam that tends to develop faulty underdrainage under cultivation, through the development of a type of hardpan. In forested areas this faulty structure does not occur. Excessive erosion occurs only under conditions of careless cultivation on slopes.

The southeastern portion, about 10 per cent of the total basin, has been sharply folded to form a portion of the Allegheny Mountains. Here several formations have been exposed. The common rock formations are limestone, sandstone, and shale of the Devonian period and the immediately overlying Lower Mississippian. The soils are loams and silt loams, which because of the steep topography are subject to considerable sheet erosion in the higher slopes and to occasional gullying in the lower areas.

CLIMATE

The mean annual precipitation over the Allegheny watershed amounts to 42.4 inches. This is distributed through the seasons as follows:

	Inches	Per cent
April, May, June	10.3	54
July, August, September	12.6	
October, November, December	10.0	46
January, February, March	9.5	
Total	42.4	

Range in mean annual precipitation over the watershed is from 36.15 inches at Pittsburgh to 51.2 at Cherry Creek, N. Y., with a maximum for any one year of 65.66 at Corry, Pa., and a minimum of 22.8 at Oil City, Pa. The range in distribution of rainfall from April to September, inclusive, is from 47.2 per cent to 60.2 per cent of the total for the year.

Annual snowfall is greatest in the northern and northwestern portion of the drainage. The least annual snowfall, 34.9 inches, is at the mouth of the river at Pittsburgh. The greatest recorded is at Jamestown, N. Y., 100.2 inches. The heaviest precipitation for a 24-hour period occurred at Saegertown, Pa., where 5.66 inches was recorded.

The mean annual temperatures for the several stations range from 44.7° to 52.6° F., with a mean maximum temperature of 61.6° F. and a mean minimum temperature of 33.8°.

Records from 15 stations widely scattered over the drainage area present the following range in extremes of temperatures for a given year: Minimum, minus 8 degrees to minus 35 degrees; maximum, 94 degrees to 103. There seems to be little or no relationship between elevation and temperature nor is a direct relationship between elevation and precipitation apparent from the records.

Even though the precipitation is well distributed by months, the winter precipitation is concentrated in the form of snow, which may melt in the spring and run off in a few days. The wide annual variation in precipitation and temperature over a period of years makes necessary an analysis by individual years properly to correlate weather and floods.

The climatic conditions preceding the greatest floods in the Allegheny may be summarized as follows:

Low temperatures in November and December before the ground was covered with snow to any depth, followed by heavy snowfall in December, January, and February. Sudden thaws in March, accompanied by 2 to 5 inches of rainfall over large portions of the basin. These conditions result in rapid run-off of rain and snow water with little or none going into the frozen ground.

The seriousness of the flood in the main stream is always tempered by the degree to which the tributaries are in flood and the extent to which the crests of the various tributary floods meet in the main stream.

HISTORICAL DEVELOPMENT

Settlement in the Allegheny Valley began prior to the Revolutionary War. Agriculture had reached a high state of development as early as 1846. By this time almost the entire lower basin had been cleared for farms. About 1800 coal mining began in the lower valley and has increased steadily since that time. Exploitation of

oil and gas began after the Civil War and the industry has now passed its peak. Lumbering did not begin on a large scale until after the Civil War. However, it developed rapidly and had passed its peak in 1885.

Land utilization is partially indicated by the following table of percentages, computed from the Census of Agriculture for 1925:

	Per cent
Area in farms, crop land	25.9
Area in pasture	22.2
Area in pastured woods	7.9
Area in woods not pastured	5.6
Area in waste land in farms	3.6
Area not classified	34.8
Total	100.0

The last item includes large areas of land in forest or at least not developed. It also includes cities, villages, and road and railroad rights of way, so that accurate separation of these items is not possible without securing more data at the source.

Ownership of land in the Allegheny drainage area in 1925 was as follows:

	Per cent
Private land	94.4
State forests	.5
National forests	5.1
Total	100.0

CONDITION OF LANDS OTHER THAN FOREST

Cultivated land occupies 25.9 per cent of the drainage area. The principal farm crops are corn, wheat, oats, hay. The grape crop is important in the northwestern portion of the basin. Dairying is carried on more or less extensively throughout the area. Orchard fruits are produced on 90 per cent of the farms. Beef cattle are not extensively raised in this section. Potatoes are grown on 70 per cent of the farms.

Cultivation devised to prevent erosion is carried on only spasmodically throughout the drainage area. Methods resorted to are contour plowing and the leaving of strips in sod between plowed strips. On a large percentage of the farms the steepest slopes are left in pasture or wood lots.

Erosion of cultivated lands in the Allegheny drainage is mainly sheet erosion. Extensive gullying is not usual. However, deposits in streams and the amount of silt carried after heavy rains indicate that severe erosion takes place.

Pasture land as it exists in the Allegheny drainage area ranges from grass land to land that is almost entirely in forest. Efforts to keep tree growth out of pastures have not been vigorous, so that many pastures revert to woodland. The condition of the grass pasture is good. Overgrazing is not extensive, the condition of most pastures indicating that their carrying capacity is not being fully utilized. The practice of burning to keep down forest growth in grazing lands is not common.

Brush lands occupy about 7 per cent of the drainage area. These are chiefly the result of repeated fires on lands formerly in forest.

Three-fourths of the brush area is in inferior hardwood species but can be expected eventually to become productive forest land. The other one-fourth is occupied by a sparse growth of grass or weeds, or by bare rock ledge, the result of fires and damage by coke-oven gases. Part of it can be replanted successfully, but much of it will remain barren for an indefinite period because of the erosion. Where fires are not too frequent a brush cover develops which tends to prevent erosion.

CONDITION OF FOREST

Originally, there were large areas of northern white pine and hemlock in the Allegheny drainage. These have practically disappeared. The prevailing forest cover is a varying mixture of hardwoods, all classed as "upland hardwoods." A few small patches of old-growth white pine and hemlock remain in the northern part of the drainage but these are so small compared to the total area that they will not be considered separately. The virgin white pine and hemlock are replaced after cutting by natural growth of beach, maple, yellow birch, and black cherry.

The upland hardwood type occupies 5,132 square miles or 44 per cent of the entire area. In the northern part of the drainage basin this type is made up of beech, yellow birch, and several maples, with a scattering of other hardwoods, beside scattered white pine and hemlock. It occurs at elevations above 2,000 feet. Elsewhere in the drainage the principal species in this type are red, white, black, and chestnut oaks, sugar maple, and red maple. Other species, such as ash, hickory, basswood, and yellow poplar, also occur in the mixture. In fact, almost all hardwoods common to the Middle Atlantic States can be found in the Allegheny drainage. Chestnut formerly occurred all through the drainage, sometimes in almost pure stands, but has now been largely killed by the chestnut blight and has been replaced chiefly by various species of oaks.

The condition of the forest after logging depends upon the severity of the cutting and upon the nature of the products removed. Usually everything that is merchantable is cut. In the forest regions near the coal mines practically a clear cutting results with a high degree of utilization. But in the northern part of the drainage, where the destructive distillation plants are operating, there is a higher degree of utilization. Cutting is more conservative in the holdings of the two largest operators in the Allegheny Valley.

If the area is not burned, a new forest cover will quickly establish itself after cutting. Subordinate vegetation is abundant, both grass and brush becoming more dense after logging. Slash is left where it falls, no attempt being made to lop or pile, though lopping of tops is being urged by the State forestry department. Most of the timber now being cut is hardwood, which is reproducing both by sprouts and by seedlings already established at the time of the cutting. This reproduction, with the trees left, assures enough ground cover to prevent erosion.

Damage by fire is apparent all through the watershed, varying with the type of forest and the season of the year during which the fires have occurred. In old hardwood stands, all ground cover and advance reproduction is killed and the older timber is usually fire-scarred in the butts. On cut-over lands fires burn with much greater

intensity because of the amount of slash left after logging. All standing timber is usually killed, but if fires are not repeated, grass, brush, and sprouts soon replace the original cover. This has been the general rule. Where fires after logging are repeated, especially in the hemlock and pine type, the land is often left denuded until berry bushes and temporary tree growth establishes itself. About 1 per cent of the basin is in this condition. Humus and litter may be entirely destroyed but builds up again provided subsequent fires are kept out. The effectiveness of protection from fire is rapidly increasing, so that burned-over land can be expected gradually to build up and increase in watershed value. Grazing is confined to fenced farm woods.

PROTECTIVE VALUE OF THE WATERSHED

SOIL

On the basis of physical soil characteristics and the amount of erosion in the watershed, the soil rating is as follows:

Area, square miles	Rating
3,861	90
7,727	80
95	60
11,683	----------

Average, 83.1.

TOPOGRAPHY

On the basis of range of altitude, steepness of slope, prevailing exposures, natural retention basins, etc., the topographic rating of the watershed is as follows:

Area	Rating
1,084	100
4,406	75
6,193	50
11,683	----------

Average, 64.1.

PRECIPITATION

On the basis of distribution, intensity, and character of precipitation, rate of snow melting, and rate of run-off, the protective value rating of the watershed is as follows:

Area	Rating
5,841.5	75
5,841.5	50
11,683	----------

Average, 62.5.

This rating is based on several complex factors. Precipitation for the entire drainage is more or less uniform. However, in winter it is concentrated over the northern half of the drainage in the form of snow, so that the run-off is delayed. When run-off does occur it is the run-off of this accumulated precipitation. Furthermore, run-off is accelerated by the frozen condition of the ground. Sudden thaws are common throughout the drainage and are followed by comparatively heavy general rains. A combination of these factors makes the general protective rating of the watershed in respect to precipitation comparatively low. An attempt has been made above to divide the area according to the variation in the intensity with which the various factors affect it.

CHARACTER OF COVER

On the basis of the area in forest and in improved lands, the protective rating of the cover in the Allegheny watershed is as follows:

Area	Rating
3, 154	50
5, 959	75
2, 570	100
11, 683	----------

Average, 73.8.

In the rating of cover the following facts were considered: 25 per cent of the drainage is actually in plowed land. The remainder is in pasture, woodlots, and wild land. The plowed land has the lowest protective value. In this same category has been placed the barren land. The brush land prevents erosion but it does not prevent the soil from freezing or snow from rapid thawing; hence, run-off is rapid in the spring. For this reason land with this class of cover has been classed with the agricultural land. The cover on the bulk of the remaining land prevents erosion and to a certain extent retards run-off. However, only a small percentage of the area can be classed as having a cover of high protective value.

An average rating for the basin of the four separate ratings gives a protective value of 70.9 for the watershed as a whole.

Soil	83. 1
Physiography	64. 1
Precipitation	62. 5
Character of cover	73. 8
Average	70. 9

CRITICAL AREAS

From the point of view of the combined influences of topography and climate the whole Allegheny watershed must be considered a critical drainage area. The condition of the forest cover is only a partial offset. Within the watershed critical areas include land too rugged to be farmed, some of which is in forest and some cut over,

land which has been cleared injudiciously, and has not yet reverted to woodland, and land which has been denuded by coke-oven fumes or other industrial gases. There are abandoned farms where planting is necessary to improve the stand as well as to protect the soil. This is exclusive of the steeper land in pasture or wood lots included in farms. If the woodlots are to be maintained, they must be protected from grazing while young growth is becoming established. Lands denuded by coke-oven gases must remain so as long as the old-fashioned type of oven is used. These lands will gradually be reclaimed as the by-product oven replaces the open type. Much work has already been done in reforesting denuded coal lands.

Of the wild forest land, 97 per cent is occupied by tree growth of some kind, including 14 per cent in brush; 3 per cent is barren; 56 per cent is in young growth with a maximum diameter of 6 inches, and the remaining 27 per cent is in tree growth over 6 inches in diameter. Planting of some of the brush land and all of the barren land will be necessary.

From a climatological standpoint, the northeastern one-third and the extreme southeastern section of the drainage are most critical, but fortunately these areas have the greatest amount of forest cover.

RECOMMENDATIONS FOR THE WATERSHED

The present area of 5,132 square miles in forest should remain in forest. This is about 44 per cent of the drainage basin. Planting and natural regeneration should increase this to about 48 per cent of the total area.

The following recommendations are based on the opinions of the five State district foresters in Pennsylvania, whose districts lie wholly or partly within the drainage area. For protection from fire, better cooperation with private landowners is necessary, as is also installation of more efficient spark arresters on railroad engines and closer supervision of logging operations. Adequate protection from fire is the one thing necessary to retain much of this watershed in forest.

The mature forest crop can be removed without damage to the watershed. While clear cutting of hardwood forest for acid wood usually results in full stocking with sprout and seedling young growth, the best results will be obtained by allowing part of the stand to mature to saw-timber size. The best cutting practice for all types of timber can not be determined without further experimental work.

There is little need for forest planting in the northern half of the drainage. From the Clarion River southward, however, the land which could be profitably planted is comparatively extensive. It consists largely of abandoned farms, coal lands, and gas-damaged areas. Two and a half million trees a year would correct this in a generation.

Better grazing control is needed on the farms where wood lots are being destroyed by stock. The minimum measures call for removal of stock at the time the young growth is becoming established following cutting.

SUPPLEMENTARY DATA

The flood problem of Pittsburgh is greatly affected by the confluence of the Allegheny and the Monongahela Rivers within the city. The watersheds of the two rivers have been treated separately in this report because of fundamental differences. Additional data on each of these rivers have greater significance when presented with those of the other river. This is especially true when Pittsburgh is considered. For this reason the additional data on the Allegheny River have been combined with those for the Monongahela River which appear in Appendix III.

BEAVER DRAINAGE AREA

(Area 2)

LOCATION AND AREA

The Beaver River watershed is a small, triangular-shaped area in northeastern Ohio and western Pennsylvania. The Beaver River joins the Ohio at its most northerly point, about 20 miles below Pittsburgh. The river is about 75 miles long, flows in a general southerly direction, and drains an area of 3,182 square miles, 1,812 miles of this lying in Pennsylvania and 1,370 square miles in Ohio.

TOPOGRAPHY

The topography of the Beaver River Valley reflects both the influence of erosion in the outer edge of the Allegheny Plateau and the influence of glaciation in the northern part of the valley. The channels of the streams are comparatively deep, giving rise to a much discussed terrain in the southern part of the valley. In the northern section the hills are more rounded and the streams more sluggish. A few bogs are found in this drainage. The basin may be divided roughly as follows:

Hilly, 30 per cent, including the nonglaciated region and that portion of the basin which lies to the north of it in Pennsylvania extending through Mercer County.

Rolling, 60 per cent, including the area in Ohio and portions of the basin along the western edge of Pennsylvania.

Plain, 10 per cent, including stream bottoms and the more level land in the glaciated section.

GEOLOGY AND SOILS

Sandstone, sandy shale, and shale are the principal rocks underlying this basin. They belong to the Upper Carboniferous period (Pennsylvanian system). A coarse sandstone and shale formation (Pottsville), and a shale, sandstone, and thin limestone formation (Allegheny) predominate. A small belt in the northernmost portion is underlain with sandstone, sandy shale, and cherty limestone. (Waverly formation, of the Lower Mississippian.)

The northern three-fourths of this basin has been glaciated. A mature dissected plateau topography had been developed prior to

glaciation, and consequently, the present topography is more rugged than that of many glaciated regions. There are, however, many level or gently rolling areas, to which has been added the effect of moraine deposits. The drift is from a few feet to a hundred feet or more in depth. In a very few areas the underlying formation has been exposed.

The glacial till has weathered to a depth of approximately 3 feet creating silt loams and clay loam soil types. These are designated as glacial sandstone and shale soils of the Volusia series. The underlying till is generally a clay loam with abundant rock fragments and boulders. Except in very flat areas, drainage is good to excessive. The silt loam type often tends to develop a hard pan on long cultivation. Erosion is not serious in the glaciated region, yet in certain small areas with unusually steep topography, as in Mercer County, Pa., washing is a problem of some significance.

The soils of the southeastern portion of the basin are residual sandy and silty loam types from sandstone and shale. (De Kalb series.) On the ridges and upper slopes, the soil type may be sandy, stony, and shallow. Under these conditions washing is common where the soils have been exposed. At lower elevations the soils are deeper, possess good drainage, and are much less subject to erosion.

CLIMATE

Records for stations in this drainage cover a period of 6 to 40 years, and show a range in mean annual precipitation from 32.78 to 41.73 inches. The precipitation is heavier in the eastern part of the area but in the neighborhood of Youngstown and Lordstown, Ohio, the mean annual rainfall in from 2 to 5 inches less than average. Snowfall is important, ranging from 41 to 58 inches. Mean annual temperatures vary from 47.5° to 50° F.

HISTORICAL DEVELOPMENT

The Beaver valley was settled about 1800, the settlers entering by way of the Ohio from Pittsburgh. Early development was largely of an agricultural character, which has become intensive since the advent of the steel industry. The entire valley from Pittsburgh northward and northwestward through New Castle, Pa., to Youngstown and Warren, Ohio, is one of the most important steel manufacturing sections in the country. This industry has attracted numbers of foreigners, and though it has provided markets for farm products has also been largely responsible for the movement of farming people to the cities. The main lines of travel from Pittsburgh to Cleveland traverse this valley.

The following estimate of the present land utilization is taken from the United States Census of Agriculture, 1925:

	Percentage of total area
Farms, cropland	36
Farms, pasture	28
Farms, woodland	11
Land not in farms	25

The last classification includes wild land, land incorporated in cities and villages, and roads and railroad rights of way.

The total estimated forest land is 18.4 per cent of the area of the basin.

CONDITION OF LANDS OTHER THAN FOREST

Agriculture has been developed intensively especially in the southern and southwestern part of the valley where the steel-producing centers furnish a good market for all farm products.

As a result of the movement of the rural population to the cities in recent years, a waste land problem of considerable magnitude has developed. The Ohio State Forestry Department recognizes the need of fire protection on the continguous wasteland areas which are producing for the most part, only weeds, grasses, briers, and inferior tree growth.

CONDITION OF FOREST

The original forest was composed of hardwoods, with small quantities of white pine and hemlock. Beech-maple and oak-hickory forests were most abundant; but chestnut, white ash, and walnut were also of considerable importance. Black ash, sycamore, soft maple, and birch were common along the streams.

Since the valley is primarily agricultural, centered about industrial cities, the forested land is restricted almost entirely to woodlots, and the lumbering operations are carried on by portable-mill owners. The tendency has been to leave the cut-over areas in very poor condition with no attempt at slash disposal or protection against spring and fall fires, which are common throughout the section. Most of the woodlots have been grazed and this, along with the poor care given them in matters of cutting and fire protection, has left them in such condition that even the forested land has little protection against soil washing. Undergrowth and reproduction have been destroyed; the woods gradually open up, become decadent, and disappear, with no new growth to replace them.

PROTECTIVE VALUE OF THE WATERSHED

The protective rating of the watershed is summarized in the following tabulations:

Soil:

2,311 square miles	90
871 square miles	80

Weighted rating for the basin, 87.3.

Cover:

218 square miles	50
1,159 square miles	60
1,219 square miles	85
586 square miles	95

Weighted rating for the basin, 75.3.

Topography:

795 square miles	75
1,857 square miles	85
530 square miles	100

Weighted rating for the basin, 85.

PRECIPITATION

On the basis of the amount and distribution of the precipitation, this watershed has been given a protective rating of 90.

Average for the basin, 84.4.

CRITICAL AREAS

Undesirable conditions in this valley result largely from the abandonment of farm land and the destructive treatment of farm woods. While there is no good opportunity for acquisition of large contiguous areas for publicly owned forests, small areas might be acquired for demonstration.

RECOMMENDATIONS

Forest-planting stock should be furnished by the State on a large scale. An educational campaign is needed to procure forest care and protection, and to show to the communities, the value of forest planting on the waste lands which are now a total economic loss.

BIG SANDY DRAINAGE AREA

(Area 3)

LOCATION

The Big Sandy River drains northeastern Kentucky, a strip of West Virginia, and three counties, Wise, Dickenson, and Buchanan, in western Virginia. This area, occupying 4,259 square miles, is apportioned about as follows: Kentucky, 53 per cent; West Virginia, 24 per cent; and Virginia, 23 per cent.

TOPOGRAPHY

The Big Sandy heads in the folded ridges which front the Allegheny plateau in western Virginia. Here the general trend of the topography is northeast to southwest in narrow, long ridges. The general exposure of the valley is to the northwest, though the deep valleys have created exposures in all directions. The slopes are steep and the courses of the streams very crooked.

About 85 per cent of the area is mountainous to hilly, 10 per cent is rolling country, and the remaining 5 per cent is in narrow flood plains. The average fall from the headwaters to Williamson, W. Va., is 20 feet to the mile; from Williamson, W. Va., to the mouth of the Ohio River it is 2 feet to the mile. Elevations range from 500 feet at the mouth of the river to about 3,500 feet at the tops of the higher ranges. The two main tributaries, Tug Fork and Levisa Fork, both flow in a general northerly direction and have cut deeply into the plateau.

The steep slope of the valley bottom results in swift flowing streams in the upper half of the drainage. In most of the upper half, the flood plains are long and narrow, averaging less than 300 feet wide; while in the lower half they spread out a mile or two

in width in many places. Quantities of silt, gravel, and coarser rock material moved at high-water stage have been dropped here and there all along the river bed. These deposits range in depth from 1 to about 6 feet. In some places this material forms long narrow islands. There are no swamps or natural reservoirs in the basin.

GEOLOGY AND SOILS

The basin of the Big Sandy lies almost entirely within the Appalachian plateau province. Coarse and fine grained sandstone, conglomerate, shales, coal, and thin limestone (of the Upper Carboniferous-Pennsylvania system) are the common underlying rocks. The coarse sandstone and quartz conglomerate (Pottsville formation) is the common ridge and summit formation. Sandstone with shale and thin limestone (Allegheny) is also a common upland formation. Fine sandy shale interbedded with thin limestone (Conemaugh) occurs near the foot of the basin.

The basin is a severely dissected portion of the Appalachian plateau. Bottom land development is scanty at the head, becoming more abundant toward the lower basin. The tops of the ridges are on the same general level as the original plain surface. Only a few upland surfaces represent remnants of the original plateau formations.

The upland residual soils from sandstone and shale (DeKalb series) are most common. The predominant soil type is a stony silt loam. The type varies with the proportion of coarse-grained sandstone or of shale. The alluvial soils in the basin represent the wash from the upland, changed by weathering under different conditions. The stony silt loam and other DeKalb types are relatively shallow. They have good to excessive drainage. Erosion on cleared land is active after the tree roots have decayed. On steep slopes the soil may be washed away to expose the underlying rock. In the lower part of the basin sandstone, red shales, and thin-bedded limestone have weathered to form a clay loam (Meigs soil series) which is deeper and of a heavier texture than the sandy upland soils. This clay-loam type is subject to washing and gullying. Because of its porous yet clayey nature it is commonly subject to landslide.

CLIMATE

The period covered by the station records in this watershed is from 7 to 34 years. These records show a mean annual precipitation varying from 42.9 to 44.73 inches, reaching a minimum of 29.72 inches and maximum of 65.35 inches. The headwaters are subject to sudden and heavy rains.

A greater quantity of snow falls in the higher country at the source than at the mouth. The mean annual fall of snow varies from 15.4 to about 31 inches, but the snow rarely stays more than 10 days and is not a material factor in the creation of spring floods. A range in mean annual temperatures has been recorded from 54.3° to 56.2° F. Winter temperatures do not usually go below zero Fahrenheit.

HISTORICAL DEVELOPMENT

The river bottoms and coves have been cleared for agriculture. The virgin forest has been largely cut over, in some cases two or three times, but a few tracts from which only the large trees have been cut can be found in the headwaters. Mining is now the principal industry. Fully 70 per cent of the area is absolute forest land, better suited to forest than any other use. Part of the area is in local ownership, in small tracts of 10 to 500 acres, and the remainder is owned by corporations interested principally in coal mining and in lumber.

Approximately 57 per cent of the area is in farms, of which 12 per cent is cropped, 20 per cent pastured, 3 per cent other land in farms, and 22 per cent woodland not pastured. Of the land pastured 5 per cent is woodland. In the Virginia section of the basin and in the headwaters of Levisa Fork in Kentucky, the percentage of forested land is higher and more of the land is held in large tracts.

CONDITION OF LAND OTHER THAN FOREST

The best of the farm land is that along the streams, and that newly cleared. In Virginia, some land has been cleared on the ridge tops. The fields which have been cleared on the hill slopes are subject to severe erosion and are abandoned as soon as the top soil has washed away. Only a small percentage of the slope land is in pasture, since grass does not grow very well on the soil which is deficient in lime and coarse in texture. Most of the hill fields are allowed to revert to forest when crops no longer pay. The steep river-bank lands and flats are maintained in corn, orchards, vegetable gardens, and pasture. Where cultivation has been carried on for a short period only, or where land has been pastured without cultivation after clearing, the soil is better and a better grass sod keeps the soil from eroding.

CONDITION OF THE FOREST

The forest is characteristic upland hardwood of the Appalachian Plateau region. The composition of the original stands was about half a mixture of oaks, with yellow poplar, basswood, sugar maple, chestnut, beech, hemlock, and half miscellaneous species including pine. The last of the virgin stand is now being cut. Some of the virgin timber has been sawed at large mills and some at portable mills, but the woods operations for the two kinds of mills have been very much alike. Usually the logs have been skidded straight down the slopes to the railroad or the mill. These skid trails have washed for several years and have then been covered by the new growth of trees, shrubs, and herbaceous plants. Mere cutting does not cause serious erosion except in the skid trails.

After cutting the logged area has considerable cover left, consisting of defective trees and those of poor species, young sprout and seedling trees, and undergrowth, chiefly laurel. The slash is usually left as it falls. This protective cover is quickly augmented by new growth of trees, shrubs, and other vegetation.

This condition is quickly changed by fire. Slash fires are hot enough to kill many of the standing trees and practically all the small growth. The exposed soil has no longer a leaf litter to protect it and the surface washes severely before it can be reclothed with sprout and seedling growth. Sheet erosion rather than gullying follows fires, since the roots of trees and shrubs are not killed by the fire and continue to bind the deeper soil in place.

The leaf litter and the humus which has formed from leaf decomposition check the initial movement of water during periods of heavy rainfall. Once the water has gathered into small streams it moves quickly into drainage channels. The loss of leaf litter through fire exposes the soil to the beating action of rain, which compacts it and reduces its water storage capacity. This condition quickly allows the formation of small water channels and the prompt passage of the water to the main drainage systems.

The recurring fires which have swept the leaf litter from these forests have also thinned the stand, reduced the annual fall of leaves, and hastened the natural decay of litter through exposure to wind, rain, and sun. The maximum density of litter on the forest floor can only be secured by increasing the density of the forest through complete protection from fire.

Grazing in the forest is not so severe as to increase erosion materially, but it does tend to keep the forest open and reduce the cover, through the browsing back of young trees and shrubs. Some fires are still set to destroy the forest and open it up to convert it to grazing land. The mistaken idea that fires induce better vegetative cover is still an important factor in their occurrence.

The darkened color of the Big Sandy is due partly to erosion of its basin and partly to the coal-mining operations. In 1925, Williamson, W. Va., and the vicinity within a radius of 20 miles had 107 active coal-mine operations, which produced 11,295,000 tons of coal. This represents 2.16 per cent of the total United States production. Within a 20-mile radius of Welch, W. Va., there are about 110 active mine operations. These instances give some idea of the magnitude of the mining operations, which has tended to dwarf the interest in the forest industry, while at the same time it has caused severe cutting for mine timbers.

PROTECTIVE VALUE OF THE WATERSHED

The large area of soils with sandy texture on the Big Sandy watershed makes the soil conditions alone comparatively favorable to water absorption. Where the forest has been cleared and the land farmed on steep slopes, the soils have washed and are now compact and thin.

Because of the steep topography this region should be largely forested. Even some of the narrow bottom-lands have been so covered with coarse rock and gravel that they are no longer suited for farming. All the steeper hills, now well covered with grass, and the land, upon which erosion has already removed the surface soil, should have a forest cover established as soon as possible, even if planting is necessary.

SOILS

From the standpoint of soils, the following protective ratings are shown:

Area in square miles	Rating
4, 134	80
35	70
90	60

Weighted average, 79.4.

TOPOGRAPHY

Per cent	Rating
85	55
10	80
5	90

Weighted average, 59.2.

PRECIPITATION

The basin of the Big Sandy is subject to more than average precipitation for the Ohio Valley, and to very heavy rains over short periods. From the point of view of precipitation, this basin must be rated at 66. This is on the basis of a mean annual precipitation of 42.5 inches, distributed irregularly through the year.

COVER

While the topographic and precipitation conditions favor floods in the Big Sandy Basin, the forest cover has done a great deal to retard their development, but fires must be kept out to allow the forest cover to become more dense and exert a more pronounced effect. About 3,000 square miles are in forest, in rather poor condition as a result of fire and cutting, 500 square miles in pasture, open or partly brush-covered, and the rest in cultivated land, cities, villages, roads, and other improvements.

Area in square miles	Rating
2, 976	90
496	80
787	50

Weighted average, 81.4.

Average rating for the basin

Soils	79. 4
Topography	59. 2
Precipitations	66. 0
Cover	81. 4
Average	71. 5

This basin is an outstanding example of the influence of forest cover in protecting very rough nonagricultural land. A good cover is essential to this land if its thin, though porous soil is to be kept from washing into the stream courses.

CRITICAL AREAS

About three-fourths of this basin, located in the rougher part of the valley above the junction of the Tug and Levisa Forks, must be considered critical because of the steep topography and the heavy rainfall. The density of the forest cover, which now only partially offsets the effects of steep topography and heavy rainfall, should be materially increased. Some lands now cleared should be in forest.

RECOMMENDATIONS FOR THE WATERSHED

An area of at least 3,300 square miles, or about 75 per cent of the total area of the basin, should be kept in forest. This will require some increase over the present area. Cultivation should be largely restricted to the lower end of the valley, and the more level valley lands. All land held for production of minerals should be utilized for the production of timber if not otherwise needed for development of the property.

Through cooperation of the landowner with the State and Federal forestry organizations the condition of all timbered or idle land should be improved.

1. By protection of the forest from fire. This will require material improvement and increase in the existing organizations.
2. By restriction of grazing on lands recently cut over, to prevent loss of the better young hardwood trees. This applies particularly to the richer cove lands.
3. By proper methods of cutting and management on areas now timbered. Poor trees and poor species should not be left standing at the time of logging. The principle of leaving the cut-over land in the best condition for growth should be recognized, and an effort made to increase the stocking of forest land with more good trees.
4. By planting on many fields which are being abandoned, to insure well-stocked stands of good species.

Fire protection is provided under supervision of the State in three of the counties of Virginia in this watershed. Some protection is provided by the larger landowners in the fourth Virginia county. The State forester of Virginia recommends extending the State organization to this county. He also says that 500,000 acres, or 79 per cent of the Virginia section of this watershed, should be kept in forest. Private owners who are holding land for mineral rights should profit by the chance to practice better methods of cutting and protection.

The State forester of Kentucky says complete fire protection is essential and recommends planting of abandoned farm lands.

Land values in this watershed are high because of mineral rights. On the other hand, surface rights are not valued too highly. Although clear title to land is difficult to secure because of the valuable mineral rights which coal companies hold, the use of the surface of the land is not greatly interfered with by the process of coal mining.

The renewal of a protective forest cover need not be discouraged therefore, on land where mineral rights are withheld and clear title is unobtainable. This is especially true where the protection of the watershed depends on the establishment of publicly owned forests.

CUMBERLAND DRAINAGE AREA

(Area 4)

LOCATION AND AREA

The Cumberland River has a crescent-shaped basin heading in Kentucky and extending southwestward entirely into Tennessee before it turns northwest across western Kentucky to the Ohio River. The river has a total length of about 350 miles, and the basin has a width of about 70 miles through most of its length. The area drained by the Cumberland is 17, 939 square miles, 7,116 square miles of this being in Kentucky and the rest in Tennessee. The principal tributaries of the Cumberland River are Stones, South Fork, Rockcastle, and Laurel Rivers.

TOPOGRAPHY

The Cumberland River drains an area approximately 360 miles in length lying in Kentucky, Tennessee, and the extreme southwestern corner of Virginia. It rises in the roughest section of Kentucky, that around Pine and Cumberland Mountains. Here the changes in topography are abrupt, the mountains rising from 1,000 to 2,000 feet above the level of the streams. Toward the west and southwest the sharp mountain characteristics are lost in more rounded, but still very hilly, topography. Even in the central basin of Tennessee the topography is hilly, but farther to the west and northwest, where the river turns back into Kentucky again, it becomes less hilly and more rolling.

GEOLOGY AND SOILS

The lower portion of this basin lies within the central plains region of Kentucky and Tennessee. Limestone, shale, and sandstone (St. Louis and Chester series of the upper Mississippian system) are the underlying formations. The surface has the billowy topography characteristic of a limestone country. Sink holes and caverns are common. Residual silt loams and sandy loams from limestone and sandy shales are the common soil types. They are of medium depth and possess good drainage, due to the rolling topography and to the cavernous nature of the underlying rock. These soils have been subject to some erosion under careless cultivation, but part of the eroded soil is merely carried to the sink holes.

The Central Basin of Tennessee makes up a portion of the Cumberland drainage. The surface structure of this area is associated with the formation of the Nashville dome, which was subsequently unroofed to form the Central Basin. In this unroofing process the younger underlying strata were removed down to the Ordovicion limestone that now forms the bedrock of the basin. The succeeding overlying formations of Silurian and Devonian period, together with the Waverly formation of the lower Mississippian, form an

irregular escarpment several hundred feet high at the edge of the basin and the broad adjoining plains known as the Highland Rim.

The soils of the Central Basin are loam and silt loam types from limestone. They are of medium depth and are fairly well drained. On abandoned farm land destructive erosion has frequently occurred. The soil types of the Highland Rim plains are thin silt and sandy loams often with abundant chert fragments present. The soils are derived from shales, sandstone, and impure cherty limestone. On steep topography they are subject to washing when exposed.

The upper eastern portion of the Cumberland drainage is within the Cumberland Plateau, and is underlain by sandstone and shale of the Pennsylvanian system. The soil types are chiefly fine sandy loams and silt loams. On the uplands and ridges the soils are rather shallow and are subject to destructive washing when exposed.

CLIMATE

From 7 to 63 years are covered in the records of the climatological stations located within this watershed. The mean annual precipitation varies from 38.26 to 60.77 inches, and the minimum and maximum from about 30 to 77 inches. In north central and central Tennessee, in the region about Byrdstown and Sparta, the rainfall is noticeably higher, exceeding 55 inches in many cases. This central area receives its highest precipitation in winter and spring, with a concentration existing along the edge of the Cumberland Plateau. The snowfall varies from about 9 to 20 inches, and increases in intensity in the northeastern portion. Mean annual temperatures have been found to range from 55.1° to 59.3° F. Warm season precipitation makes up from 47.2 to 53.9 per cent of the total for the year.

HISTORICAL DEVELOPMENT

In the early logging operations in this region the best individuals of the more valuable species, such as yellow poplar, were culled out. The poor transportation facilities, however, and the necessity of floating the logs down the river gave some protection to the heavier species, such as oaks. Also in the most inaccessible and remote coves of the mountain section of the upper Cumberland, stands of virgin timber remain, some of them the best to be found anywhere. On the rest of the basin the forest has been severely culled and cleared. Logging, fires, and grazing have hindered satisfactory reestablishment of the desirable forest types. Most of the land has a high value because of its minerals, and most of that in the upper reaches of the basin is held by coal companies, which formerly gave little thought to the betterment of the forest, but some of which have recently adopted fire-protection measures to assure themselves of a supply of timber in the future.

The early settlement and development of the Nashville Basin led to land clearing. Even the hilly Highland Rim section surrounding the Nashville Basin has been cleared for farming more rapidly than either the eastern or western ends of the Cumberland Valley.

Because of the widely differing topography of this valley, its present development is summarized by sections.

I. Cumberland Plateau: Although culled and burned severely there are still large contiguous areas of good timber. The land is largely owned by coal companies in extensive tracts. Agriculture is not important, lumbering and mining having somewhat displaced it.

II. Highland Rim: The country is less rugged than the region of the Cumberland Plateau, and farming on the upland limestone soils is more important. The forests are found in smaller areas and lumbering is of less importance. The hilly character of the topography invites erosion where soils are exposed.

III. The Central Basin of Tennessee: Agriculture is very important on the rich limestone soils. The topography is rolling, a low plateau which is in general 400 feet below the level of the rim. The forests are found in small areas and the clearing stage has passed.

IV. The lower Cumberland Valley in western Kentucky: An area along the Tennessee-Kentucky line is very important to agriculture, being the most extensively farmed section of the watershed. The land on the lower courses of the Cumberland below this section is quite hilly and forests claim a greater portion.

V. Percentage distribution of land in this basin.

	Per cent of total area
Farms:	
Crop land	26
Pasture	20
Forest	40
All other land	14

CONDITION OF LANDS OTHER THAN FOREST

The development of mines, lumbering, factories, and public roads has attracted many of the younger people away from the more rugged farms. The hilly fields with thin soils have been worked until the initial fertility acquired from the forest cover has been lost. The erosion which began under cultivation continues on most of these fields after they are abandoned. These fields return slowly to a forest after a period during which weeds and scrubby tree growth occupy them. The mountain section of the Cumberland Basin has suffered most from cultivation of steep fields. Abandonment of land is common throughout the valley.

The highland rim country produces more abundantly than the mountainous section. The soils in general contain less siliceous material and more limestone and are better adapted to farming. More level topography creates better agricultural conditions, but there are many ill-cared-for slopes which are subject to erosion. General farming is the rule, with some specialization in tobacco and fruit.

In the central basin of Tennessee the brown limestone soils are fertile and highly prized for general farming, in which tobacco, wheat, corn, oats, potatoes, and some fruit are most important. Even here, however, erosion has destroyed fields along the main drainage channels. Along the lower course of the Cumberland below

the central basin the country becomes more hilly again and less desirable for agriculture.

CONDITION OF FOREST

The upland hardwood type occupies practically all the flat land along the streams. The chief species of this type are white oak, chestnut oak, chestnut, yellow poplar, beech, maple, and basswood. On drier ridges and southern slopes the black oaks and some pine are found. The effect of lumbering, fire, and grazing has been to increase the proportion of inferior species in the stand. Artificial drainage is not practiced to a material extent.

The bottom-land type, composed for the most part of sweet gum, sycamore, honey locust, poplar, elm, and pin oak, is found only in a very limited area bordering the lower Cumberland and a few of its tributaries. Hemlock appears to some extent along the streams in the upper Cumberland, and in the central basin of Tennessee there is a concentration of red cedar.

The effect of lumbering in this bottom-land type has been to increase the proportion of sweet gum in the stand. The cutting must be done in the dry summer and fall season, and this tends to prevent to some extent the immediate regeneration of the oaks by sprouting. Where the cutting is heavy the lands are left in very poor condition and a rank growth of brush and weeds tends to hinder the prompt return of a good stand. Under such conditions sweet gum can sometimes come back quickly enough to occupy the site.

Fire in the fall season is important on cut-over lands. It removes the heavy litter, and the surface of the soil below becomes very hard, making seedling reproduction more difficult. This is especially detrimental to the white oaks, which germinate in the fall.

The present forest is one which has been subject to severe culling, clearing, fire, and grazing. Inferior species and poor individuals of the desirable species predominate, except on a few inaccessible tracts.

PROTECTIVE VALUE OF THE WATERSHED

	Per cent of area	Rating
Soil:		
Appalachian plateau	30	80
Limestone uplands	69	70
Alluvium, loose, Illinois drift	1	50
Weighted scale rating, 73.		
Physiography:		
Mountainous	40	50
Hilly	40	75
Rolling	15	85
Flat	5	90
Weighted average, 67.		
Precipitation:		
General average precipitation, 48.5 inches.		
Distribution, medium, 50 per cent of area.		
Distribution, poor, 50 per cent of area.		
Scale rating on this basis, 69.		
Cover:		
Farms, cropland	26	60
Farms, pasture	20	75
Forest	40	90
All other	14	55
Weighted average, 75.		

Protective value of the entire watershed:

Soil	73
Physiography	67
Precipitation	69
Cover	75
Weighted average for the drainage	71

This average loses much of its significance because the stream crosses the topographic and precipitation provinces in its westward course. These provinces cause great variation in the protective value of different portions of the watershed.

CRITICAL AREAS

The major portion of the headwaters of the Cumberland River to the point where it emerges from the Highland Rim in Tennessee is in need of a protective forest cover because of its rugged topography, thin soil, and relatively heavy precipitation. The deep dissection of the Cumberland Plateau leaves very little land in this region suitable for either cultivation or pasture. Other steep hill lands on the west side of the Nashville Basin, which are part of the western edge of the Highland Rim, also require forest cover to protect them from erosion.

Even the farmed section of this basin contains many fields which should have remained under forest cover and which are adding materially to the silt burden of the river.

RECOMMENDATIONS

The Cumberland Plateau and Highland Rim parts of this basin contain large areas of land suitable for publicly owned forest. On the east side of the Cumberland Plateau in Kentucky are two areas which have already been designated for organization into national forests. Seventy-five per cent or more of the Cumberland Basin should be included in a complete system of State or Federal fire protection. Abandoned fields which are not adequately restocking should be replanted. This will require the cheap production of planting stock by State or Federal Government. Coal companies and lumber companies should be encouraged to maintain their timberlands in a producing condition. The forest of the Cumberland Plateau is in very poor condition as a result of cutting and fire, and the land is not suitable for extensive grazing because of its light soil. Prof. George Roberts, of the Kentucky State Agricultural College, recommends increase in size of farms and proper care of the woodlands included in them.

STATEMENTS

The following is quoted from an article by Prof. George Roberts, Kentucky College of Agriculture, in the Southern Agriculturist, November 15, 1926:

> The average size of the farm in the 34 mountain counties (of Kentucky) is 82 acres total, of which 37 acres are classed as improved land; that is, land in pasture and crops for harvest. Of the improved land, there is an average of only about 17.5 acres of crop land per farm in the region * * *.

The first suggestion that I would offer is that it is highly desirable that the size of the farm should be largely increased and that all of the land that is not adapted to crops and pasture land should be reforested and cared for according to the best forestry practice. The conditions of supply and demand for timber in this country will certainly make good timber profitable by the time a new crop can be produced. It is quite true that the harvest seems too long deferred to be attractive to people who need money now, yet land covered with a promising growth of young timber will be a valuable asset that should give a good profit on the outlay and effort required to produce it, if it is necessary to sell it before the timber is large enough to cut.

The following summary of hydroelectric projects was compiled by the Tennessee Geological Survey:

GREEN DRAINAGE AREA

(Area 5)

LOCATION AND AREA

The Green River drains an area of 8,948 square miles in west central Kentucky and 381 square miles in Tennessee, a total of 9,329 square miles. The river rises just south of the bluegrass region in Kentucky, flows first west and then northwest, joining the Ohio about 30 miles above the mouth of the Wabash. The two principal tributaries are the Rough River from the north and the Big Barren River from the south. The valley of the Green River is about 165 miles long and averages about 75 miles wide. It is roughly rectangular in shape.

TOPOGRAPHY

The Green River drains the greater part of the western coal field, which is a region of hills with sunken, silt-filled valleys. In the lower part of the basin flat land predominates. This is subject to overflow by water backed up through flooding in the Ohio. The central part of the Green River Basin is hilly with narrow stream channels. At the head of the basin a rolling limestone area encircles the western coal field. This has sink-hole formations and in some places is entirely subsurface drained. The actual range in elevation varies from 390 feet at the mouth to about 1,800 feet at the head.

The entire drainage slopes gently toward the Ohio, giving a general exposure to the northwest. Most of the tributaries have moderate velocities. The roughest area lies along the river in Butler and Edmonson Counties, where the valleys are steep and narrow. The heads of the tributary valleys are often narrow and rocky. The gradient of the main river from Mammoth Cave to the mouth is about 1.5 feet per mile. Many of the numerous sink holes have no outlets and act as small storage basins, which accounts for the numerous springs in the limestone section. The main river has been slack watered for a distance of 200 miles by means of six dams with an average lift of 14 feet, and the Barren River has been made navigable to Bowling Green by means of one lock. Recently the city of Louisville filed an application with the Federal Power Commission for a permit to develop power by constructing a 150-foot dam near Mammoth Cave.

The topography of the entire drainage falls into the following rough classification:

	Per cent of area	Area
		Sq. miles
Hilly	75	6,997
Rolling	18	1,679
Plains	7	653

GEOLOGY AND SOILS

The northwestern portion of this basin lies within the western coal fields of Kentucky, which is, geologically, a part of the Appalachian Plateau. The underlying formations are sandstone, shale, and coal of the Upper Carboniferous period (Pennsylvanian system). In Henderson, Daviess, and McLean Counties and a part of Ohio County, the underlying rock has had little influence on the character of the soils. Here the soils are from a surface mantle 6 to 10 feet deep of fine silt loam probably of glacial origin. The remaining soils of the western coal fields are residual fine sandy and clayey loams of only medium depth. Erosion may be severe under careless management or exposure.

The portion of the Green River Basin bordering the coal field lies within the Central Plains region of Kentucky. The soils are chiefly silt loams from St. Louis and Chester limestone of the Upper Mississippian. They are of medium depth with fair drainage and are not particularly subject to erosion except under careless cultivation or exposure.

A small area in the eastern end of the Green River Basin is underlain with the sandstone, shale, and cherty limestone of the Waverly formation of the Lower Mississippian. The area includes a portion of the poorest land that is farmed in the State. The soils wash and erode badly.

CLIMATE

Records kept at stations within this drainage basin covering periods from 6 to 42 years show that the mean annual precipitation varies from 42.79 to 52.08 inches. Minimum and maximum records by years during the period show approximately 30 and 66 inches, respectively. The spring season shows a somewhat higher rainfall along the southern edge of the watershed. The warm season precipitation ranges from 45.9 to 50.2 per cent, with only one station exceeding 50 per cent. Mean annual snowfall in the Green River Basin varies from 12 to about 18 inches. Mean annual temperatures have been recorded as low as 55.2° and as high as 58.6° F.

HISTORICAL DEVELOPMENT

This part of Kentucky was originally stocked with a great variety of valuable hardwoods. Its accessibility and the value of the land for agriculture early marked the forest for destruction. The rolling and less rugged areas of the Green River had been well cleared by 1830.

The demands of the great sawmills that grew up at Evansville and other places on the Ohio and the easy transportation down the Green River resulted in the clearing of much land unsuited for agriculture. Much of this land eventually reverted to forest. The present status of land utilization for the entire drainage is indicated by the following data, compiled in part from the Census of Agriculture for 1925:

	Per cent
Farmland:	
Crop land	33.0
Woodland pasture	4.0
Other pasture	23.0
Woodland not pastured	13.6
Waste land in farms	9.4
	83.0
Other land:	
Wild land	12.0
Cities, towns, and rights of way	5.0
	17.0

Total forest land, 29.6 per cent.

Lumbering reached its height about 1907, and Holmes[1] reported in 1911 that practically no virgin timber remained in the region.

Coal mining in the western Kentucky field is increasing in importance and can now be classed as one of the most important industries of the drainage, second only to agriculture.

With the exception of the large holdings of the mining companies, most of the ownership is in farm tracts of 160 acres or less.

CONDITION OF LANDS OTHER THAN FOREST

Farming is well diversified and crop rotation is the established practice. Corn, tobacco, wheat, and hay are the principal crops. The rich alluvial loams of the broad valleys are usually free from erosion. The upland soils wash badly when carelessly cultivated, but are generally in good condition. Grazing is important over most of the drainage, but is well regulated and does not contribute materially toward soil erosion.

Abandoned fields constitute a considerable aggregate area in the more rugged portions of the drainage. These are frequently badly washed and are not restocking to a satisfactory extent.

CONDITION OF FOREST

Holmes describes the forests of this region as being divided into two general types on a topographical basis, the bottomland and upland forests. The bottomland type is more valuable, but confined to a much smaller area than the upland.

The bottomland or lowland hardwood type, as it is now generally called, is an association of red gum, oaks, hickories, and maples, with a smaller admixture of elm, ash, hackberry, willow, sycamore, cypress, black gum, and yellow poplar. Sweet gum is widely distributed. After heavy cutting in this type, the forest is usually left

[1] Nineteenth Biennial Report, Bureau of Agriculture, Labor, and Statistics, State of Kentucky, 1911. "Sweet gum seems to be specially adapted to these lands and should be encouraged in every way possible."

in very bad condition. The wetter areas quickly become densely stocked with a brush cover which hinders natural restocking. Slash fires are common on the drier sites and result in a scanty stand of oak and scrubby hickory. Fall fires are frequent. Besides their direct effect in destroying young growth, they remove the litter and harden the surface of the soil in the drier situations, rendering it unfit as a seed bed, especially for the species that germinate in the fall.

The upland hardwood type[2] is characterized by the predominance of the black oaks and hickory. The white oak has been heavily culled and is of inferior quality. Black, Spanish, scarlet, red, and post oaks, and hickory are of the greatest importance on the slopes and ridges. In the hollows and coves, beech, maple, gum, elm, and ash are also found. The characteristic underbrush consists of sassafras, red maple, dogwood, and black oak sprouts. In its present condition, the upland forest is open and irregular, with a more or less grassy floor. It has been heavily lumbered, and consequently the average size of the trees is small.

Fire is one of the chief factors in the deterioration of this type. It allows the reproduction of the inferior black oaks and post oak to make headway against the more valuable but less fire-resistant species. In addition, it weakens the larger trees and destroys the much-needed humus in the soil.

The most important effect of grazing on fenced woodlands in this region is the destruction of reproduction. Hogs are particularly fond of the sweet acorns of the oaks, and as a result of this the oaks are unable to establish themselves in a desirable proportion.

PROTECTIVE VALUE OF THE WATERSHED

SOILS

Square miles	Protective rating
2,799	80
5,784	70
746	50

Weighted average, 71.

TOPOGRAPHY

Square miles	Protective rating
6,999	70
1,676	90
654	95

Weighted average, 75.

PRECIPITATION

The annual precipitation of 47.5 inches is well distributed, and has been rated at 76.

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[2] Nineteenth Biennial Report, State of Kentucky, 1911.

COVER

Square miles	Protective rating
3,078	60
2,519	75
2,426	90
1,306	55

Weighted average, 71.

For the purpose of rating cover, all woodland pastures have been considered as pasture, as they are usually of such open character that they more nearly approach the condition of pasture lands.

Average rating for the basin

	Protective rating
Soils	71
Topography	75
Precipitation	76
Cover	71

Average, 73.

CRITICAL AREAS

The hilly portion of the western coal fields of Kentucky, which occupies the central part of this basin, is primarily a forest country, the soils and topography being ill suited to cultivation. The ditching of the silt-filled valleys of the lower basin allows quick drainage of flood waters into the Ohio. When forested these flats held flood water for weeks. This is one of the drainage projects which has increased the flood stages of the Mississippi. Further drainage in this valley will add to this effect. The hills above these flats should be protected from clearing on slopes so steep that erosion will be sure to follow.

The limestone land which surrounds the western coal fields was not heavily forested all over, even in virgin condition. Oak openings occurred in parts of the sink-hole country. Some fields are eroding even in this region, and the future treatment required will depend on whether agricultural practice succeeds in keeping sod on fields too poor for other crops. Good pasture can only be maintained through fertilization and resort to clover or other nitrogen-fixing crops. Where such practice is not adopted severe erosion of abandoned fields will probably occur. The extreme head of the basin in the east and southeast is hilly and poor agriculturally. A high percentage of forest cover is needed to preserve the thin soils.

RECOMMENDATIONS

The hilly section of the western coal fields should be kept largely in forest, publicly owned in part. Organized protection from forest fires is needed over all the area where large blocks of forest are contiguous. Coal companies and other owners of considerable areas of forest land should be encouraged to maintain forest cover in productive condition. Abandoned fields should have a good sod cover restored for pasture purposes or should be planted with trees.

GUYANDOT AND TWELVEPOLE DRAINAGE AREA

(Area 6)

LOCATION AND AREA

The area drained by the Guyandot River and Twelvepole Creek, covers 2,354 square miles and lies entirely within the State of West Virginia. The greater portion of the drainage lies within the Appalachian Plateau, and is flanked on the east by the Kanawha and on the south and west by the Big Sandy. The drainage basin is about 80 miles long by 30 miles wide. The Guyandot flows into the Ohio at Huntington, W. Va., while Twelvepole Creek has its mouth about 15 miles below, just above the mouth of the Big Sandy.

TOPOGRAPHY

The topography of the Guyandot and Twelvepole drainage is rolling to mountainous. Practically all of the flood plain is confined to the frontage along the Ohio. A short distance back from the Ohio the low rolling country gives way to the much-dissected Appalachian Plateau. The actual range in elevation varies from 505 feet at Huntington to 3,693 feet at the head of the river in Wyoming County.

Slopes are as a rule steep, except in the lower reaches. Ridges are frequently knife-edged, as is typical of dissected plateau country. The entire drainage slopes gently toward the Ohio, giving a general exposure to the northwest.

The comparatively narrow drainage tends to give the tributaries moderate velocities. From the headwaters of the stream to the "roughs" in Wyoming County the fall is moderate, but below the "roughs" to the mouth it is about 3 feet per mile. There are no swamps or natural reservoirs. The main river has been slack-watered for 50 miles by means of several dams.

The topography of the entire basin falls into the following rough classification:

	Per cent of area	Area
		Sq. miles
Mountainous	50	1,177
Hilly	45	1,059
Rolling	5	118
	100	2,354

GEOLOGY AND SOILS

This basin is a severely dissected plateau lying within the Appalachian Plateau province. No extensive upland areas remain of the original plateau formations. The valleys tend to be steep and the ridges sharp. Coarse and fine grained sandstone, conglomerate, shale, coal, and thin limestone of the upper Carboniferous (Pennsylvanian), make up the underlying formations.

Coarse sandstone and conglomerate (Pottsville) make up the common ridge and summit formation in the eastern portion of the basin. In the northwestern portion, sandstone and shale with coal and thin limestone, and coal formation (Conemaugh) are more prevalent.

Flood plain and bottomland are lacking in the upper streams and are but poorly developed along the main drainage in the lower part of the basin.

The upland residual soils from sandstone and shale (De Kalb series) cover most of the area of the basin. The common soil type is a stony silt loam, which varies with the amount of coarse-grained sandstone or of shale that enters into the soil formation. These soils are relatively shallow, with excessive drainage. They wash badly on the ridges and upper slopes. The underlying rock is often uncovered by the removal of the finer particles by erosion.

The soils of the northwestern portion of the basin are derived from thin-bedded shales and sandstone that have given rise to a clay loam type (Meigs soil series). Soils of this type are deeper and heavier than are the more sandy soils of the uplands. They are often severely gullied on sloping land, and on steep slopes are commonly subject to landslips and landslides.

CLIMATE

In this watershed climatological records cover periods varying from 9 to 27 years. These records show a range in mean annual precipitation from 42.50 to 51.04 inches, and give minimum and maximum extremes of rainfall at approximately 31 and 65 inches, respectively. The influence of elevation is noted in increased precipitation in the headwaters. This is especially pronounced during the summer season, warm weather precipitation making up about 53 to 55 per cent of the annual total. The mean snowfall for the year varies from about 21 to 25 inches. Records of mean annual temperatures show a variation of 54.6° to 57.8° F.

HISTORICAL DEVELOPMENT

The rich alluvial lands along the Ohio River were being cleared as early as 1790. The best lands were cleared first; and all timber, except a small amount for building and some which was rafted down the river, was rolled together in heaps and burned. By the close of the Civil War clearing had extended to the narrow strip of bottomlands along the principal streams in the upper portion of the drainage.

Lumbering started in a modest way about 85 years ago with the floating of the better species down the Guyandot to markets at the mouth. Extensive logging did not come until about 1870, with the advent of the railroad. With the introduction of the first band mill in 1880, operations became more extensive, and the heavy stands in Wyoming County were tapped about 1890. Lumbering reached its height about 1910 and has been steadily declining since that time. Practically all of the virgin timber had been removed by 1921. The present status of land utilization for the entire drainage is indicated by the following data, compiled in part from the census of agriculture for 1925:

	Per cent
Farm land:	
Crop land	12.7
Woodland pasture	5.4
Other pasture land	12.6
Woodland not pastured	17.6
Waste land in farms	3.7
	52.0
Other land:	
Wild land	40.5
Cities, towns, rights of way	7.5
	48.0

Total forest land, 63.5.

There is considerable coal development in the southern portion of the drainage and a considerable portion of the large holdings are in the hands of mining or speculative companies. The lower portion of the drainage is chiefly in small holdings of 160 acres or less.

CONDITION OF LANDS OTHER THAN FOREST

Farming is confined chiefly to the lower half of the drainage, with narrow strips of clearing along the flats of the larger streams in the upper half. The principal crops are corn, potatoes, hay, oats, apples, and peaches. Grazing is important over much of the area.

Erosion on farm lands is not a serious problem in the lower end of the valley. Considerable land cleared after logging in the upper drainage proved unfit for agriculture, washed badly, and was subsequently abandoned. This land is quickly covered with a rank growth of brush which checks but does not entirely prevent erosion. Open grazing is not intensive enough to reduce site quality materially.

CONDITION OF FOREST

North and west of Logan the timber is almost entirely confined to farm woodlots or small tracts. South and east of this town the drainage is practically all forested. Browning, State fire warden of West Virginia, states that 90 to 95 per cent of the upper reaches of the Guyandot is absolute forest land.

The original stand was heavy for hardwoods, averaging over considerable areas about 6,000 board feet per acre. The principal species were yellow poplar, walnut, oaks, chestnut, white ash, black cherry, hickory, and in smaller amounts, basswood, beech, maple, black gum, white gum, sycamore, hemlock, cucumber, pitch pine, and black locust.

The entire drainage has been cut over at least once and in some places as much as four times. With the exception of lands cut over for mining timbers, most of the area contains a fair stand of oak. Skid trails on steep slopes have washed badly. Slash fires have been of common occurrence and repeated fires have resulted in material lowering of the site quality.

The rapid restocking of cut-over lands to some form of cover has controlled erosion and tended to equalize streamflow in the upper drainage, though conditions are far from ideal. The Guyandot above

Logan is clear practically the entire year, while below this town even a slight shower suffices to make the tributaries muddy and the main stream cloudy.

PROTECTIVE VALUE OF THE WATERSHED

SOILS

Square miles	Protective rating
1,483	80
871	60

Weighted average, 73.

TOPOGRAPHY

Area in square miles	Protective rating
1,177	50
1,059	70
118	90

Weighted average, 61.

PRECIPITATION

	Protective rating
Distribution:	
Medium	75
Poor	65

General average of precipitation, 47.5 inches.
Weighted average, 70.

COVER

	Protective rating
Cropland	60
Pasture	75
Forest	90
Improvements	50

Weighted average, 79.

For the purpose of rating cover all woodland pastures have been considered as pasture as they are usually of such open character that they more nearly approach the condition of pasture lands.

Average rating of the basin

	Protective rating
Soils	73
Physiography	61
Precipitation	70
Cover	79

Average, 71.

CRITICAL AREAS

The higher portion of the plateau lying within this watershed has comparatively thin soil, very rugged topography, and rather heavy precipitation. The upper half of the plateau, therefore, and, in addition, the steeper land in the central portion of the basin, must be considered critical.

RECOMMENDATIONS

A large block of land lying in the headwaters of the Guyandot and also in the Tug Fork of the Big Sandy is now largely forested and should remain in this condition. This is the logical area within which purchase of public forests should be made. At the present time it contains no public forests.

KANAWHA DRAINAGE AREA

(Area 7)

LOCATION

The Kanawha River enters the Ohio from the southeast between the Guyandot and Little Kanawha Rivers. Its drainage area comprises 12,303 square miles and extends in an irregular shape south and east, including most of the southern half of West Virginia, a strip through western Virginia, and a small area in North Carolina. This river divides the Cumberland from the Allegheny Plateau, cuts through the Appalachian Valley, and heads in the west side of the Blue Ridge near Blowing Rock, N. C.

The main tributaries of the Kanawha from the north and east are the Pocatalico, Elk, Gauley, and Greenbrier Rivers. Except the Pocatalico, these rivers rise in the high country in central and eastern West Virginia. From the south and west the Coal, Bluestone, and New Rivers enter the Kanawha, draining the large coal fields of West Virginia.

TOPOGRAPHY

The New River, which joins the Gauley to form the Kanawha, rises in a mountainous region west of the Blue Ridge in North Carolina, passes through the rolling land of the valley of Virginia, and enters the plateau region of West Virginia. The other tributaries of the Kanawha rise largely in this plateau, which has not only been deeply cut by the streams but has passed well into the mature stage of erosion.

The mountainous parts of the drainage basin along the eastern boundary of West Virginia are the remnant of the plateau, while the hills and rolling land of the rest of the basin in West Virginia are more severely eroded and have less resemblance to plateau structure. The gorge of the Kanawha River itself is deeply cut into the plateau and has very steep to precipitous sides. The topography may be roughly classified as: Mountainous, 75 per cent; hilly, 10 per cent; rolling, 10 per cent; and plain, 5 per cent.

The Kanawha River has an elevation of 515 feet at its mouth and the New River has an elevation of about 3,700 feet at its source in North Carolina. The fall within the drainage basin is, therefore, about 3,000 feet.

The Kanawha Valley opens generally to the northwest, but the irregular dissection of the drainage basin causes exposure of slopes in all directions. The general northwesterly slope of the drainage basin from the Appalachian region gives it a location in the southern edge of storms passing up the Ohio Valley.

The long period of erosion of this basin and the freedom from interference by glaciation has created a well-established system of drainage. The fall of the main river varies from 1.1 feet per mile at its mouth to 11.3 feet per mile from Hinton to the Virginia-West Virginia State line. The fall is less rapid through the Virginia section of the New River but increases to 14 feet per mile for the section from the junction of the North and South Forks to the source.

Velocities in the tributaries generally increase toward their sources, where they are swift. The lower 90 miles of the river from a point near Montgomery to the Ohio has been made navigable by means of 10 locks and dams. The main Kanawha is a slow-flowing stream with rapid main tributaries. Drainage over the basin is good. There are few swamps and no natural lakes.

The flood plain of the river is only about 1½ miles wide at the mouth and becomes still narrower within the plateau above Charleston. All tributaries have narrow stream beds with small flood plains at some of the bends and stream junctions.

Though very little of the potential water power of the Kanawha River and its tributaries has been developed, the swift character of the streams, and the deep, narrow gorges through which they flow make possible an extensive development of water power.

An estimate based on the average flow and a plant efficiency of 70 per cent shows that the maximum potential water power of New River from the forks in North Carolina to the head of navigation near Montgomery is 960,000 horsepower and the minimum 280,000 horsepower. The tributaries of the New and Kanawha Rivers are also important sources of water power.

The abundance of natural gas, oil, and coal in West Virginia has delayed the utilization of the water power of Kanawha River and its tributaries, but the increasing cost of natural fuels and the gradual exhaustion of the resources of gas and oil has turned the attention of power users to the undeveloped power of this stream. Applications have already been made to the Federal Power Commission for permits to develop about 200,000 horsepower on New and Kanawha Rivers. At present the capacity of installed water wheels in water-power plants on New River is not more than 40,000 horsepower.[1]

GEOLOGY AND SOILS

The western half of this basin lies within the Appalachian Plateau province. The underlying formations are of the Upper Carboniferous period—Pennsylvanian. Coarse sandstone and conglomerate make up the common summit and ridge formation (Pottsville). Sandstone, shale, and thin-bedded limestone compose another extensive formation (Allegheny). Sandy shale with thin limestone (Conemaugh formation) predominates in the northwestern part of the basin. Coal is commonly present in these formations with the exception of the Pottsville. The upland plateau soils are predominantly of a stony silt loam type from sandstone and shale (DeKalk series). They are shallow and excessively drained. They wash badly on ridges and upland slopes when exposed or cultivated.

In the lower portion of the basin, clay loams and loams from shales, sandy shales, and thin limestone are the predominant soil

[1] Water-Supply Paper 536. U. S. Geological Survey, p. 3.

types. These are of medium depth and good drainage. When exposed on slopes, they are subject to gullying. On very steep slopes landslides frequently occur.

The eastern portion of West Virginia in this basin is underlain by sandstone, limestone, and shale of the Lower Carboniferous and Devonian periods. The soils are of loamy type with varying amounts of silt, sand, and clay. When they are injudiciously cultivated some erosion may occur. As a rule, however, grass grows well in this area, and cleared or abandoned areas when sodded are not subject to washing. Part of the Appalachian Valley lies in the Kanawha drainage. Here the underlying formations are of limestone, sandstone, and shale of the Ordovician and Upper Cambrian periods. The soils are silt and clay loams of medium depth. Erosion is not serious except under careless management or on exceptionally steep slopes.

The extreme southern portion of the basin lies within the older Appalachian Mountain region. The formations are of quartzite, shale, slate, and sandstone, with a small area of granite, gneiss, and schists. In this region the soils are of two general types. At lower elevations clay types predominate. These are derived from slates, shales, or schists. These soils are not porous and allow a very rapid surface run-off. They gully badly when exposed. At higher elevations quartzite, granite, and gneiss have given rise to shallow stony silt loam types which suffer badly from sheet erosion when exposed on ridges and upland slopes.

CLIMATE

The Kanawha drainage lies in an area where the mean annual precipitation ranges from 37.53 to 64.38 inches. This has been determined from records made within the watershed covering a period of 5 to 45 years. The lowest and highest extremes of precipitation (minimum and maximum) were found to be approximately 22 and 88 inches, respectively. Approximately 49.2 to 59.9 per cent of the precipitation comes in the warm season. In the headwaters in North Carolina and in a restricted area in southwestern West Virginia rainfall is excessive, and practically the entire region is subject to comparatively high precipitation. A peculiarity exists with regard to snowfall. In the headwaters and across the valley of Virginia it is of little consequence, but in the plateau country of West Virginia there is a noticeable increase, as much as 69.6 inches having been recorded. This area is concentrated in the eastern part of the plateau, and as the Ohio River is approached the snowfall again decreases materially. The amount of water storage in the form of snow is small when compared with the total precipitation of the basin, and the snow offers little protection against deep freezing of the ground. Mean annual temperatures vary from 48.5° to 55.3°.

HISTORICAL DEVELOPMENT

The chief industries thus far developed in West Virginia have been agriculture, mining, and lumbering. Each of these has exerted an influence on the present condition of the forests.

Clearing of land for agricultural purposes began about 1800, chiefly along the streams. Subsequently, clearing was carried on in the higher plateau region including some ridge and slope land. Erosion has seriously reduced the fertility of agricultural lands except those of the flat stream bottom or more level plateau areas. On the steeper hillsides, the practice has been to clear land, cultivate it for a few years, and then seed it down for pastures. Such pasture lands are soon invaded by brush, which must be cut periodically to maintain the grass cover. Some of the pasture lands that have become worn out and have been abandoned have grown up to brush and trees.

The chief influence of mining (largely for coal) has been to cause a close cutting of timber in the vicinity of the coal mines. Lumbering operations have removed trees 12 inches and over in diameter; and the smaller material down to 5 inches in diameter has been used for mine ties and timbers. This has resulted in comparatively clear cutting of extensive areas and repeated culling in others. This heavy cutting started erosion, but the cut-over areas, unless pastured, were quickly restocked with forest trees.

The outstanding example of clear cutting was for the production of charcoal in connection with the earlier iron industry. The best stands of second-growth timber are now found on land once stripped of its timber and allowed to grow up without special treatment. Where these stands have escaped injury by livestock and fire they form an excellent forest cover.

Lumbering has been an important industry in the area for about 50 years and has been extended during the past 25 years as a result of the construction of railroads for the development of coal fields and for logging. The practice in logging has been to remove only sound trees of the better species 12 inches and above in diameter. This has tended to maintain a partial forest cover at all times on cut-over lands unless they were subsequently burned.

Below Charleston, W. Va., and in the Appalachian Valley ownership is mostly in farms. Elsewhere in the drainage there are larger tracts of land held by lumber companies and mining companies.

Within the Kanawha drainage basin, 4,673,884 acres out of the total of 7,873,920 acres are in farms. About 12 per cent of the total area is in crops, 27 per cent in pasture, and 57 per cent in forest cover. About 25 per cent of the woodland in the farms is pastured. The percentage of cultivated land is greatest in that part of the drainage basin which is in the valley of Virginia.

CONDITION OF LAND OTHER THAN FOREST

Corn, wheat, oats, and other cereal crops constitute the chief products of cultivated land. Hay and pasturage, with a small amount of orchard, take up the rest of the improved land. Sheet erosion quickly reduces the fertility of cultivated land on all but the more level fields. Some of the worked-out fields are seeded to grass and maintained in pasture as long as the grass crop is good. The steeper land continues to erode and lose its fertility until only brush

and weeds occupy it. The fields are then abandoned and allowed to grow up to trees. Fields not seeded when cultivation ceased are subject to severe erosion until brush cover checks it.

CONDITION OF FOREST

The forests of this drainage basin are about 98 per cent upland hardwood. The remainder of the area is covered by forests of spruce, hemlock, and northern white pine.

SOFTWOOD FORESTS

The spruce forest, which occupies the higher plateau lands, has been cut very heavily, both saw timber and plupwood being utilized. Following lumbering, a very heavy slash which covered the logged area served to check erosion, but also constituted a very serious fire hazard. Most of the spruce slash eventually burned over. Skidding trails which ran up and down the slopes started erosion channels during the first few years following logging. Spruce, pine, and hemlock land, which has not been burned over, has a duff soil that absorbs water very readily, and even after one fire is soon covered again with berry bushes, wild red cherry, and aspen. As a result the land is not exposed to erosion for a long period. On some tracts where very little soil existed, the destruction of humus by fire has left only bare rocks. Such land is, of course, permanently devastated.

Grazing is not important in this type of forest.

UPLAND HARDWOODS

The upland hardwood forest, which is composed of oaks, hickories, chestnut, poplar, beech, birch and maple, basswood, black cherry, and a considerable number of other species, has been logged rather heavily following the advent of logging railroads. In practically all cases, reproduction by sprouts or young seedling trees followed very quickly after logging operations, and this young forest growth soon restored the cover of leaf litter to the soil. In this type of forest, no effort is made to dispose of slash and, especially in the higher types, slash fires are very destructive to young growth. Immediately following a fire which destroys the second-growth forest, berry bushes and young hardwoods that sprout from the roots of the dead trees reestablish a cover. Only where soils are thin will the exposure of the soil result in serious erosion. Some erosion takes place during the first and second years following fires in this type. Deterioration of the upland forest type is caused by grazing as well as by fire. Wherever cut-over lands are inclosed by fences and heavily pastured, erosion occurs in direct proportion to the degree of stocking. Tramping causes erosion of the surface soil and this prevents the establishment of a grass cover. Cut-over lands that have never been plowed, reestablish a cover of grass and withstand erosion better than cultivated land that has been abandoned without seeding to grass.

PROTECTIVE VALUE OF THE WATERSHED

	Per cent of area	Rating
Soil:		
Appalachian plateau	39	80
Limestone area of eastern West Virginia	21	80
Appalachian Valley	18	70
Unaka and Blue Ridge	12	60
Permian and late Pennsylvanian	10	60
Weighted average		74
Topography:		
Mountainous	75	50
Hilly	10	75
Rolling	10	85
Flat	5	90
Weighted average		58

PRECIPITATION

General average of precipitation, 41.5 inches, unequally distributed over the watershed.

Weighted average, 65.

COVER

	Per cent of area	Rating
Cropland	12	60
Pasture	27	75
Forest	57	90
All other	4	55
Weighted average		78

Protective rating of entire watershed

	Per cent of area
Soil	74
Physiography	58
Precipitation	65
Cover	78
Weighted average	69

CRITICAL AREAS

In the plateau region of West Virginia the rough topography, thin soil, and high precipitation make a forest cover necessary on all land except the stream bottoms, bench lands, and more rounded ridges. The bluffs of the river and its tributaries are steep and should be kept in forest. Cultivation has been carried on over too much of this rough land, especially in the lower end of the Kanawha Valley. In the limestone areas of the central part of the basin good pasture sods protect the soil on all but the ridges. In the headwaters of the basin much of the topography is too rugged for cultivation. Nearly all of this basin in its present state is incapable of exerting its maximum effect in prevention of run-off.

RECOMMENDATIONS

Increased acreage of publicly owned forest.

Increased protection from fire over all the forested part of the watershed. This may be provided by State agencies working through the present county or association organizations.

Assurance of regeneration following cutting through protection of all forest land from fire and grazing.

Improvement of the forest by removal of the soil portion of the stand to allow thrifty young trees to establish themselves.

Planting both on publicly owned and privately owned lands which are not restocking. This calls for organized distribution of planting stock at low cost by State or Federal Government.

Organization of wood-using industries on a permanent basis to encourage proper forest management.

Although the land in the greater part of this basin is obviously better suited to forest crops than to any other use, economic factors have prevented an organized effort to use the land for timber growing. In part this is due to a lack of information. Research in the problems created by fire, in methods of forest management, in planting, and in the control of injurious agents are needed for the promotion of good forest practice.

STATEMENT OF RUN-OFF

Discharge of Kanawha River at Lock No. 2, Montgomery, W. Va. For years ending September 30, 1889 to 1918, inclusive:

Average for the 30-year period:	Run-off in inches
October	1.02
November	1.04
December	1.56
January	2.52
February	2.66
March	3.62
April	2.73
May	2.07
June	1.56
July	1.16
August	.96
September	.67
Annual	21.57

KENTUCKY DRAINAGE AREA

(Area 8)

LOCATION AND AREA

The Kentucky River rises in Letcher County, Ky., at the boundary between Kentucky and Virginia, and flows in a general northwesterly direction, entering the Ohio at a point about 70 miles below Cincinnati.

Practically all its course is through a deep gorge which has many tortuous crooks and several large bends. The basin is irregular in shape, about 175 miles long, and 60 miles wide at the upper end. The entire basin, 6,945 square miles, lies in Kentucky.

TOPOGRAPHY

Approximately half of the drainage, or, roughly, the area north of the foothills through Lincoln, Rookcastle, and Jackson Counties, lies in the bluegrass region. This is a comparatively rolling to hilly area, ranging from 850 to 1,000 feet in elevation. Through the lower portion of its basin the Kentucky River has cut a gorge averaging about 300 feet in depth, with nearly perpendicular walls of limestone throughout most of its course. Because of the close proximity of the Kentucky to the western rim of its drainage basin, relatively few streams enter from the west. They are short and have a much steeper gradient than those entering from the east. This condition also results in giving the western and northern portions of the basin a generally western exposure. Through this region the Kentucky has an average fall of approximately 0.9 foot to the mile.

Southeast of the bluegrass region the topography becomes more rugged and mountainous. Elevation ranges from 625 feet on the river at Irvine, near the edge of the Appalachian Plateau, to more than 3,000 feet along the Pine Mountain fault. This region has typical dissected plateau topography with narrow V-shaped valleys and short ridges, the tops of which are nearly on the same level.

The gradient of the three forks of the Kentucky which drain the higher plateau is much greater than that of the main stream. The average fall is about 2.1 feet to the mile from Hazard, Hayden, and Manchester to the junction near Beattyville. Above these points the forks themselves split up, and the slopes increase rapidly.

For the entire drainage the topography can be subdivided as follows:

	Per cent of area	Square miles
Mountainous	60	4, 167
Hilly	20	1, 389
Rolling	15	1, 042
Plains	5	347
Total	100	6, 945

The range in elevation for the whole basin is from 475 feet at the mouth of the Kentucky to more than 3,000 feet along the Pine Mountain fault. Relative elevation between stream bottom and ridge top rarely exceeds 400 feet in the lower valley, but frequently reaches 1,500 to 1,800 feet in the eastern plateau. There is practically no flood plain throughout the entire course of the Kentucky.

There are no natural reservoirs or swamps in the drainage. Slack-water dams have been constructed along the 225-mile stretch between Beattyville and the mouth of the river. These consist of 14 locks and dams whose average lift is about 16 feet. Dix River has been investigated for its water-power possibilities, and a report concerning it is contained in Kentucky Geological Survey Bulletin 21, Series 28. A dam has now been built on the Dix. King[1] estimates that the

[1] Surface Waters of Kentucky, Kentucky Geological Survey, series 6, vol. 14, 1924.

entire drainage of Elkhorn Creek can be controlled by an impounding dam three miles above its junction with the Kentucky. He states that the capacity of this reservoir would be 128,000,000 cubic feet.

GEOLOGY AND SOILS

The lower half of the basin of the Kentucky lies within the bluegrass region. Limestones, shales, and calcareous sandstone make up the underlying formations. The soils are residual silt loams and clay loams of high fertility. The topography permits good drainage except in the limestone sink hole section of the bluegrass region. The soils are extensively cultivated, and subject to some erosion especially in the shale belt.

A belt of knobs crosses the middle of the basin just southeast of the bluegrass border. This belt is geologically the broad escarpment of the strata overlying the Ordovician and Silurian limestones, exposed at the time the Cincinnatian geoanticline was unroofed to form the bluegrass region. Here resistant cherty limestones and sandstone overlie the shales, which are more easily weathered. This belt constitutes one of the poorer sections of the basin. The soils are stony and thin. The topography is broken and the region is considered poor for cultivation. The soils suffer severely from washing when exposed.

The upper half of the Kentucky River Basin is within the Appalachian Plateau. This region has been severely dissected and only occasional remnants of the original plain remain. It is underlain by conglomerate sandstone and shale formations with coal. The upland residual soils are stony loams and silt loam types. These are relatively shallow and suffer badly from erosion on the ridges and steeper slopes.

CLIMATE

Records of climate in the Kentucky drainage area cover a period of 7 to 63 years. The mean annual precipitation ranges from 39 to to 52.37 inches and the minimum and maximum rainfall is 17.49 inches and 63.33 inches, respectively. About 50 per cent of the precipitation occurs during the warm season. Rainfall over the whole area is high, creating at times a heavy run-off and erosion. Snowfall is of less importance, the annual snow fall being from 13 to 24 inches. Mean annual temperatures range from 54.9° to 56.8° Fahrenheit.

HISTORICAL DEVELOPMENT

The bluegrass region and valleys in the lower edge of the Cumberland Plateau were first settled about the close of the Revolutionary War. Settlers came in from the mountain region to the east. Clearing of agricultural land progressed rapidly. In the rougher part of the Cumberland Plateau both the valley bottoms and ridges in the gaps were settled. Later the slope lands, especially in cove heads, were cleared and cultivated. These steeper lands have since been abandoned because of washing.

Lumbering started with the rafting or floating of the lighter species down the streams to the Ohio. In 1840, Kentucky produced

lumber to the value of $130,329. The greatest production was reached in 1907, with a cut of 912,908,000 board feet and an estimated value of $19,291,498. By 1920 the cut had dropped to 421,100,000 board feet, valued at $17,627,000. The Kentucky drainage was logged early and has not been heavily culled for the better species. It has been estimated[1] that 60 per cent of the entire upper Kentucky region is absolute forest land and should be kept in timber cover.

Coal mining in this basin is largely in the speculative state. Large tracts are being held for their mineral value, but because of the excessive faulting over much of the area, actual production under present economic conditions is not profitable.

The present condition of land utilization for this drainage is indicated by the following data compiled in part from the census of agriculture for 1925.

	Per cent
Farms:	
Cropland	21.0
Woodland pasture	5.2
Other pasture	31.8
Woodland not pastured	14.3
Waste land in farms	2.7
Total	75.0
Other land:	
Wild land	19.4
Cities, towns, rights of way, etc	5.6
Total	25.0

From the above figures the percentage of forest land for the drainage was set at 39. This figure was derived as follows:

	Per cent
Woodland pasture	5.2
Woodland not pastured	14.3
Wild land	19.4
Total	38.9

Ownership in the lower valley is almost entirely in farms of 160 acres and larger. On the upper valley approximately 50 per cent of the land is owned outright by coal, timber, and speculative companies. The remainder is held principally by small owners in tracts of 200 acres or less.

CONDITION OF LANDS OTHER THAN FOREST

The principal industry in the Kentucky Basin is livestock production, chiefly cattle and horses, and, to a lesser extent, sheep and swine. Cultivated land, the greater portion of which is in the northern counties, occupies 21 per cent of the drainage area. The principal farm crops are corn, hay, and tobacco.

Cultivation has been a considerable factor in causing erosion on hill lands of the eastern plateau and the Eden shale belt of the bluegrass, as is evidenced by the muddy character of the streams. The coming in of forest on abandoned fields in some sections has reduced the rate of damage. Success in keeping bluegrass sod on pasture

[1] Nineteenth Biennial Report, Kentucky Bureau of Agriculture, 1911.

lands depends upon fertilization with phosphate and lime and rotation of some nitrogen-fixing crop.

CONDITION OF FOREST

The original forest was composed of oaks, yellow poplar, basswood, sugar maple, chestnut, beech, pine, and other species. Lumbering has ceased to be of great importance even in the headwaters of this basin. Bruner [2] in 1914 classified the upper reaches of Kentucky as follows:

	Per cent
Virgin	5
Lightly culled	10
Culled	35
Cut over	30
Total	80

Fletcher [2] in 1921 reported that little change had occurred in the area of forest since 1914 with the exception of the forest in the counties bordering on the bluegrass region. He stated that in these counties practically all of the forest had been cut over by 1921.

The prevailing practice of culling the forest for the better species, leaves a stand that is thin and poor. Fires keep down the reproduction and destroy the litter. No disposal is made of logging slash and this intensifies fires when they occur. One fire can destroy the accumulated benefits of many years of protection.

Only 13 per cent of the forested area in farms is grazed. Where a compact sod is maintained by bluegrass, grazing in this region does not contribute materially toward soil erosion. It does, however, keep the accumulation of litter in the forest to a minimum, and thereby reduces the fertility of the site. In the rugged parts of the plateau open range grazing is still common but is not important from the protection-forest standpoint.

PROTECTIVE VALUE OF THE WATERSHED

SOILS

This drainage area is almost equally divided into the fertile silt and clay loams of the limestone region, of good protective qualities, and the thin, stony, and silt loams of the upper plateau, which erode badly on steep slopes. The soils of the bluegrass region have been rated at 85, because of their porous structure, which permits good drainage. The poorer soils of the Appalachian plateau are eroded more readily, chiefly because of their thinness and the influence to topography. A rating of 70 have been given these soils because of their shallow depth and physical characteristics. An average rating of 75 is fixed for the basin.

TOPOGRAPHY

From the table given under the heading "Topography," and rating the classes as follows—mountainous 50 per cent, hilly 70 per

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[2] Unpublished report of Forest Service.

cent, rolling 90 per cent, plains 100 per cent protective—the average rating on the basis of topography was determined.

Square miles	Protective rating
4,166	50
1,390	70
1,039	90
350	100

Average rating, 62.5.

PRECIPITATION

A rating of 70, based on the distribution and amount of rainfall shown in Table 3 of the appendix, is given this watershed.

COVER

Regrouping the classes, in the table of land utilization, by cover classes, the following values are derived:

Square miles	Protective rating
1,458	55
2,222	80
2,709	90
556	50

Average rating, 76.3.

The protective ratings assigned each class were determined as follows: Improvements were classed at the lowest rating because the run-off is practically 100 per cent in cities, towns, rights of way, etc.; cultivated land was given a slightly higher rating because of the fact that the land supports a vegetative cover over a portion of the year; pasture land was rated high in this drainage because of the excellent sod maintained by bluegrass; forest cover was rated at 90 because of the culled condition of the stands.

Average rating for the basin: Soils, 75; physiography, 62.5; precipitation, 70; cover, 76.3; average, 70.9.

CRITICAL AREAS

Practically the entire drainage basin of the Kentucky River is in poorer condition to retain flood waters and prevent erosion of soil than when covered by its original forest. About 50 per cent of the basin is agriculturally developed and will remain in crops and pasture. Some of the steeper fields of the eastern plateau, the Knobs, and the Eden shale belt will be abandoned when too seriously eroded to be of further agricultural use. These lands, which are must detrimental from a flood and erosion standpoint, should be returned promptly to good sod or forest cover.

The hilly lands of the Knobs, the Eden shale belt, and the plateau, though forested, have a reduced protective value as a result of cut-

ting, fires, and grazing. The protective value of these forests can be increased by proper management including efficient protection from fire.

RECOMMENDATIONS

Two areas, are recommended as regions in which extensive public ownership is desirable. The first area includes all of Wolfe and Lee Counties, and portions of Menifee, Powell, Estill, Jackson, Owsley, Breathitt, Perry, Knott, and Letcher Counties, within the Kentucky watershed.

The other area, known as the Pine Mountain area, embraces the entire Pine Mountain fault from the Virginia line westward to the Bell-Whitley County line, the extreme southwestern corner of Letcher County, that portion of Harlan County north of Pine Mountain, all of Leslie County, and the entire Red Bird watershed the eastern Clay County.

The Knobs region consists of tracts too small and scattered to justify Federal, or even extensive State acquisition. The problem here is better education, fire protection, and possibly some small demonstration tracts under some form of public ownership. An effective plan for liberal extension work and for distribution of planting stock at low cost will materially further forest improvement.

Since either a good sod or forest cover must be maintained on the steep hills of this watershed, experimental work which will make land classification possible is a necessary first step.

LICKING DRAINAGE AREA

(Area 9)

LOCATION AND AREA

The Licking River drains an area of 3,742 square miles in northeastern Kentucky. The watershed is narrow at its head in the plateau region of eastern Kentucky and is also narrow at its mouth where it flows into the Ohio opposite the city of Cincinnati. The valley is about 140 miles long and 50 miles wide at its center. The river has one main tributary, the south fork, which heads in the northeastern part of the inner bluegrass region of Kentucky. While the general course of the stream is straight, its channel is tortuous, especially in the upper half.

TOPOGRAPHY

About 50 per cent of the Licking drainage area, that portion known as the bluegrass region, is rolling to hilly. Relative elevations in this region are usually not over 300 feet between stream bed and ridge top.

Southeast of the bluegrass region the topography becomes more rugged and broken in the dissected plateau area. Here the relative elevations frequently reach 500 feet, slopes are usually steep, often precipitous. Practically all of the tributaries flow in narrow valleys,

bordered by high sandstone cliffs. The actual range in elevation for the drainage varies from 510 feet at the mouth to over 2,000 feet at the headwaters in Magoffin County.

The drainage area is long and narrow, consequently the tributaries are short and have steep gradients. The average fall for the river from Salyersville to the mouth averages about 1.5 feet to the mile. The prevailing exposure is northwest. There are no water storage developments in the drainage, and no swamp or other natural reservoirs. Several attempts have been made to slackwater the Licking for navigation purposes, but no such projects have been completed.

For the entire drainage the topography can be subdivided as follows:

	Area	Square miles
	Per cent	
Mountainous	35	1, 310
Hilly	30	1, 123
Rolling	30	1, 123
Plains	5	187

GEOLOGY AND SOILS

The lower portion of this basin is entirely within the bluegrass region. The underlying formations are limestone, shales, and calcareous standstone (Cincinnatian limestone formation). This region has been evolved by the unroofing of the Cincinnati geoanticline and the removal of the overlying strata down to the Ordovician formation. Residual silt loams, clay loams, and fine sandy loams comprise the principal soil types. They are of medium depth, 4 to 10 feet, and are fairly well drained because of the rolling topography. They are not ordinarily subject to erosion except in the hilly sections created by outcrop of Eden shale.

A narrow belt crosses this basin from southwest to northeast just above the bluegrass region. Here the underlying formations are of cherty and impure limestone, shale, and sandstone of the Devonian and Lower Carboniferous periods. The soils of this belt are thin silt and clay loams. They are of medium depth and fair drainage, but often quite stony. This region and the severely dissected border of the plateau constitute one of the poorest agricultural regions in the State. The topography is broken and rough, and the soils subject to extreme washing.

The upper portion of this basin lies within the Appalachian Plateau and is underlain with the sandstone and shale formations of the Pennsylvanian system. The soils are silt and sandy loams, sometimes stony. Frequent rocky outcrops occur. The soils are not deep and are subject to extreme washing when exposed on steep slopes. Erosion frequently takes place as rapidly as the soils are formed.

CLIMATE

Climatological stations located in this watershed have kept records for periods varying from 6 to 36 years, and during this time the mean annual precipitation has been found to vary from 39.87 to 49.73

inches. The lowest and highest annual precipitation during the period was found to be approximately 26 and 70 inches. Records show that 50 to 55 per cent of the precipitation comes during the warm season. The autumn is the driest of the four seasons, the precipitation during the other three being fairly evenly distributed and much higher. Mean annual snowfall for the entire area varies from about 16 to 23 inches, the effect of altitude being noted in the increase in snow in the headwaters. Here the annual precipitation is also higher, especially in the vicinity of Farmers and Mount Sterling, Ky. Over the whole area the precipitation is comparatively high, making it important with regard to run-off and erosion. Mean annual temperatures vary from 54.5° to 55° F.

HISTORICAL DEVELOPMENT

The bluegrass section of the Licking was settled just following the Revolutionary War. Farming was well established in this section by 1837, and at that time the first unsuccessful attempt was made to open the river to navigation. Settlement later extended into the plateau. Bruner[1] estimates that about 30 per cent of the upper reaches has been cleared at one time or another. Of this, he states that half has been abandoned and has largely reverted to timberland.

The present status of land utilization for the entire drainage is indicated by the following data, compiled in part from the census of agriculture for 1925:

	Per cent
Farm:	
Crop land	21.0
Woodland pasture	6.2
Other pasture	40.8
Woodland not pastured	12.4
Waste land in farms	3.6
	84.0
Other land:	
Wild land	10.4
Cities, twons, rights of way, etc	5.6
	16.0
Total forest land	29.0

Lumbering reached its height about 1907, and the larger operations had ceased by 1921. There are no active mining operations although a number of companies are holding land with coal indications, especially in Morgan County.

Ownership in the lower half of the drainage is almost entirely in farms of 160 acres and larger. In the more heavily forested area of the upper half of the basin, considerably over half is in small holdings.

CONDITION OF LANDS OTHER THAN FOREST

Livestock production and farming are the two principal industries. Pasture land occupies 47 per cent of the drainage and crop land 21 per cent. Most of the crop land is in the lower half of the basin. Cattle and horses, and to a lesser extent sheep, are grazed in this

[1] Unpublished report of Forest Service.

region. The principal agricultural products are corn, tobacco, and hay.

With the decline of lumbering in the upper forested portion of the drainage, farming has become the most important industry. The agricultural lands are found in narrow strips along the streams or in patches along the more rounded or flattened ridge tops, in the gaps and cove heads. The soil is generally thin, and therefore easily worn and eroded. Much of this thin soil should be kept in pasturage or returned to timber. Care must be exercised against overgrazing, as a good sod is difficult to establish and maintain.

CONDITION OF FOREST

The orginal forest was a mixed hardwood type composed of oaks, yellow poplar, basswood, sugar maple, chestnut, beech, and other species. The original average stand has been estimated at about 6,000 board feet per acre. The average stand on cut-over land is about 2,000 board feet per acre.

Logging practice has been similar to that in other parts of the Cumberland Plateau. No effort has been made to dispose of slash, fires have been common, and skidding trails down the slopes cause some washing of soil before they are again closed by vegetation.

PROTECTIVE VALUE OF THE WATERSHED

SOILS

The soils of the Licking drainage fall into three general classes; the limestone soils of the blue-grass region, the thin, stony soils of the Knob region, and the easily eroded stony and silt loams of the Appalachian Plateau. The drainage area has been given a rating of 72 on the basis of this soil classification.

TOPOGRAPHY

Square miles	Protective rating
1,309	55
1,123	70
1,123	90
187	95

Average rating, 72.

PRECIPITATION

On the basis of the amount and distribution of precipitation this basin has been given a rating of 71.

COVER

Square miles	Protective rating
785	55
1,526	80
1,087	90
344	50

Average rating, 75.

Average rating for the basin: For the whole basin the average of the ratings for the four factors is 72.2, which indicates a detrimental influence on erosion and run-off. This is true, however, over only part of the basin.

CRITICAL AREAS

The upper half of the Licking Basin and also the steep lands along the banks of the main river are in need of protective cover. These include the thin soiled hills known as the Knobs and the severely dissected plateau lands. Hilly lands in the Eden shale belt present the problem of abandonment of fields due to erosion.

RECOMMENDATIONS

Bruner [1] in his reconnaissance report on the area in 1914, recommended Federal acquisition of lands in two areas. These two areas cover most of the upper reaches of the Licking and extend over into the Big Sandy and Kentucky drainages.

The total area recommended in the Licking drainage is 324,000 acres.

Bruner in 1914 stated that while there were considerable coal indications in the recommended areas, the ore veins were shattered and patchy to the extent that mining would now be impractical. A recent report from the State forester of Kentucky, however, states that the "Underlying coal beds make lands in Upper Licking too valuable for State or National holdings."

Fletcher [2] states that, "While there are some good coal measures in the southern portion of the unit, it is not thought that this would greatly hamper acquisition."

There are no recent data available on land values for these mineral areas.

The irregular and patchy Knobs region is a critical area in which the contiguous forest land acreages are too small and too scattered to justify attempts to organize large forest properties. The forested areas of the Knobs region are more suited to organization as demonstration forests.

LITTLE KANAWHA DRAINAGE AREA

(Area 10)

LOCATION AND AREA

The Little Kanawha River is tributary to the Ohio at Parkersburg, W. Va., and drains an area of 2,382 square miles in central West Virginia. The basin is narrow at the source and at its mouth, and widest at a point about one-third of its length up from the mouth. The valley is about 80 miles long and 54 miles across at the widest place. The stream follows a tortuous course practically throughout its length.

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[1] Unpublished report of the Forest Service.
[2] Unpublished report of the Forest Service, 1921.

TOPOGRAPHY

The entire drainage basin is rough and hilly, being a much dissected part of the Appalachian Plateau. The hills often converge to sharp peaks, with ridges only a rod or two in width. The valley walls of many of the smaller streams rise preciptously 100 to 400 feet above the stream bed. Most of the streams have narrow V-shaped valleys. In general the region resembles mountain land on a lower scale. The bottom land along some of the larger streams attains a width of from one-half to 1 mile. The lowest point within the area is the junction of the Little Kanawha and Ohio Rivers at Parkersburg, 564 feet above sea level. The elevations of hilltops range from 800 or 1,000 feet above sea level near the west end of Wood County to 1,900 or 2,100 feet in the eastern part of Braxton County. The highest part of the basin is at the headwaters in Webster County, where there is an elevation of about 2,800 feet. The course of the stream is extremely tortuous. The valley runs in general in a northwesterly direction. There are no swamps or natural reservoirs in this area.

GEOLOGY AND SOILS

This basin lies entirely within the Appalachian Plateau and is underlain for the most part with interbedded sandstone, shales, and thin limestone (Monongahela formation), and black shales, thin limestone, and coal (Permian formation). There are also small areas of Conemaugh sandstone, shale, and coal, and sandstone and shale of the Pottsville and Allegheny formations in the eastern end of the drainage.

In the western portion the principal soil type is a clay loam from standstone and red shale (Meigs soil series). Generally the soils of this western portion are of medium depth and fair drainage and are cultivated extensively. However, they are subject to gullying when exposed. On steep slopes, landslips and slides sometimes occur.

The upland soils of the eastern portion of the basin are stony silt loams and loams from sandstone and shale (DeKalb series). These soils are relatively shallow and are subject to severe washing when exposed on steep topography.

CLIMATE

Climatological records cover a period of 4 to 36 years. The mean annual precipitation for this drainage area varies from 39.14 to 46.93 inches. The highest and lowest amounts in one year are 68.64 and 23.44 inches, respectively.

From approximately 51 per cent to 54 per cent of the mean precipitation for the year comes during the six warm months. Snowfall records indicate a variation from about 23.4 to 35.8 inches. Snow becomes an important factor toward the headwaters. Mean annual temperatures vary from 53.4° to 54.3° F.

HISTORICAL DEVELOPMENT

Pioneers came into this area in the latter part of the eighteenth century, but rapid settlement did not occur until the opening of turnpikes from Virginia during the early years of the nineteenth century.

The construction of the Baltimore & Ohio Railroad, which entered this valley about 1854, and its subsequent extension by the means of branch lines, was an important factor in developing much of this region.

During the opening of the valley much timber was cut and burned in clearing the land for agriculture. Large quantities of yellow poplar, pine, and other timber were rafted down the Little Kanawha in the early days of land settlement. The opening of railroads into the area stimulated large-scale lumbering and so much timber was cut that at the present time practically no virgin forest is left.

Agriculture was the early industry in this valley. In general only the bottom lands, the gentler slopes, and the tops of the ridges were cleared for farming operations, the steeper slopes being left in timber.

The oil industry has become of primary importance throughout most of this valley. Coal mining on a small scale is also carried on.

Land utilization in the Little Kanawha Valley may be summarized as follows:

	Per cent
Farms:	
Crop land	15.0
Pasture	42.5
Woodland	25.0
Area not in farms	17.5

The total forested area, including both woodland on farms and wild areas, has been estimated at 38.5 per cent. Twenty-three per cent of the woodland in this valley is pastured.

CONDITION OF LANDS OTHER THAN FOREST

The principal crops are corn, hay, and potatoes. Cattle and sheep raising are important. Many of the hillsides are kept in permanent pasture. Bluegrass pasture is abundant in some sections.

On some of the steeper cultivated slopes the practice is followed of leaving strips of sod on the hillsides between the plowed areas. These strips of sod follow the contour of the slope, and help check erosion.

CONDITION OF FOREST

Originally the steep slopes and rough hilly topography of the Little Kanawha were protected by a good stand of hardwood, principally of oaks and yellow popular. Other species which were abundant in this virgin forest were hickory, ash, chestnut, beech, sugar maple, and black walnut. On the drier hills and south slopes pitch pine occurred. Hemlock along the streams and some white pine were also to be found.

SOIL

Square miles	Protective rating
598	80
1,784	60

Weighted average for the valley, 65.

COVER

Square miles	Protective rating
357	60
1,001	75
786	90
238	50

Weighted average for the valley, 75.

Most of this virgin forest has been culled, cut, or cleared. A few small tracts of original forest still remain, mostly near the eastern edge of the valley. The larger areas of culled and cut-over forest which remain are so thinned and modified by cutting, fire, and grazing that they can not exert their maximum influence on stream flow and soil protection. More than half of the remaining forest is in farm wood lots, which comprise a rather large area in the aggregate but which, on account of their condition, are not exerting their maximum beneficial influence. Wood lots are usually located on the steeper and less accessible parts of the farms. Locust often occupies the hillsides after cutting operations.

The lowered protective value of the woodlands on this drainage is due not only to heavy culling, but also to grazing, which is practiced on many of the wood-lot areas, with its usual effects of destroying young growth and opening up the forest. Because of the isolation of most of the wood lots, the fire hazard is small throughout most of this area.

PROTECTIVE VALUE OF THE WATERSHED

The protective value of the watershed has been rated as follows:

TOPOGRAPHY

The topography of the valley is all rough and hilly, with the exception of a negligible amount of land along the bottoms of the larger streams. The protective value of the watershed on the basis of topography has been rated at 70.

PRECIPITATION

The protective value of the watershed with regard to the amount and distribution of precipitation has been rated at 66.

AVERAGE RATING OF THE BASIN

	Protective rating
Soils	65
Physiography	70
Precipitation	66
Cover	75
Average	69

CRITICAL AREAS

The rapidity of the run-off has been increased in this area by clearing. Most of the steeper slopes, however, have been left in forest. In addition, a large proportion of the farm acreage is pasture land. The forest or sod cover has helped throughout the area to check erosion, which would otherwise be severe because of the rugged topography. On some parts of this watershed, where soils are sandy and slopes steep, surface washing leaves the soil too poor to support a good grass cover. These should be in forest cover.

RECOMMENDATIONS

The only areas of land suitable for acquisition as State or Federal forests in the drainage are on the headwaters of the Little Kanawha. Here a small portion of this drainage might be blocked in with areas from the Big Kanawha and Monongahela watersheds. There are also small areas which might be suitable for municipal forests. However, Parkersburg is the only large town in this area, and it is at the extreme western end of the basin. Most of the forest area is in farm wood lots, and any improvement of forest conditions within them is to be sought principally in educational measures. To reach the owners of these forest lands an active forest-extension campaign is necessary.

The steeper slopes throughout the area should be maintained in forest, or reforested if denuded. Grazing should be controlled, especially in the hillside forests; and planting should be encouraged by distribution of planting stock.

MIAMI DRAINAGE AREA

(Area 11)

LOCATION AND AREA

The Miami is a small but important tributary of the Ohio which drains 3,925 miles of southwestern Ohio and 1,427 square miles of eastern Indiana. The stream flows south from the Maumee Basin and lies between the valleys of the Wabash and the Scioto.

TOPOGRAPHY

The surface of this valley is rolling in the northern and central portions, somewhat hilly in the southern. The area may be divided about as follows: Mountainous 0, hilly 10 per cent, rolling 55 per cent, undulating and level 35 per cent.

The Miami River has its source in the Lewistown Reservoir, in Logan County, Ohio. The river channel is 163 miles long. In this watershed there are greater extremes in elevation than in any other portion of the State. The slopes are more uniform and the surface is more rolling than in the Muskingum Valley. All of the streams flow at rapid rates. Between the reservoir and DeGraff, a distance of 26 miles, the rate of fall is 3.5 feet per mile; between DeGraff and

Piqua, 27 miles, 4.4 feet; between Piqua and Dayton, 33 miles, 3.3 feet; between Dayton and Hamilton, 44 miles, 3.6 feet per mile.

One of the eastern tributaries, the Mad River, heads in the elevated tract near Bellefontaine, which is the highest point in Ohio, 1,550 feet. The other headwaters, including the Whitewater, in Indiana, have their sources at an elevation of about 1,000 feet. The Lewistown Reservoir is 968 feet above sea level and contains 6,134 acres. The area of its watershed, exclusive of the reservoir itself, is 101 square miles.

The valleys of the main river and tributaries, as far down as the vicinity of Dayton, are narrow postglacial channels. The streams in this drainage system seldom reach very low stages in seasons of drought, for the valleys are usually filled with a gravelly or sandy deposit, which furnishes strong springs. Swamps are not large in extent. There are numerous small isolated areas of wet upland soils which can not be classed as swamp. This stream and several of its tributaries afford valuable water powers. In 1880, a total of 9,431 horsepower was developed in 290 mills and manufacturing plants on the Miami and its tributaries.

Since 1913, artificial reservoirs have been developed by the Miami conservancy district at Germantown, Taylorsville, Huffman, Englewood, and Lookington. These are maintained to catch flood water and have a capacity estimated as sufficient to remove any possibility of serious floods in the future. In addition to the conservancy reservoirs, several dams were constructed as feeders for the old Miami and Erie Canal.

GEOLOGY AND SOILS

This entire basin is underlain with limestone and shale. In the upper portion, the limestone is of the Niagara formation of the Silurian period. In the lower basin, the Richmond and Cincinnati limestones of a still older period (Ordovician) predominate. The entire region has been glaciated. The southern tier of counties, however, was not reached by the Wisconsin drift. As a consequence, this southern area shows less result of glaciation and its topography is quite hilly. The remaining upper basin is level to rolling, becoming more flat toward the north.

The soils have been derived from a limestone glacial drift, which covers the entire basin. Silt loams and clay loams are the predominant soil types in the upper basin. These have been derived from the glacial till, which has weathered under conditions of fairly good drainage. (Miami soil series.) Glacial lake beds and their accompanying shore lines are common in this basin. In the glacial lake beds the drift has weathered under swampy conditions and a characteristic soil, rich in organic matter, has resulted. (Clyde soil series.)

Where the topography is sufficiently rolling the soil drainage is fair because of the large quantity of rock fragments commonly present. The more level areas have poorer drainage, and drain tile has been resorted to on cultivated land.

In the southernmost counties the soil is of a very fine loesslike texture, and consequently is more subject to erosion. On the steeper hills calcareous slates have been exposed. Where this occurs erosion has removed the finer soil material as rapidly as it has been formed.

CLIMATE

A range in mean annual precipitation from 33.69 to 45.29 inches is shown by records at stations in this watershed covering a period of 6 to 55 years. The mean precipitation varies from approximately 22 to 62 inches. From 51.6 to 60.6 per cent of it comes during the six warm months—April to September. In general an increase in the amount of precipitation can be noted toward the southern part in the vicinity of the Ohio River. Snowfall data show a variation from about 18 to 34 inches. Mean annual temperatures from 49.7° to 52.7° F. have been recorded.

Serious floods have been frequent in the Miami Valley, culminating in the disastrous flood of 1913 in which the city of Dayton and numerous smaller towns were inundated with a loss of 400 lives and a $100,000,000 in property. Though the drainage of swamp lands, tiling, cultivation of farms, and the destruction of forests have tended to increase the run-off since the settlement of the valley, the severe floods that sweep down the valley are due primarily to the great storms which occur at irregular intervals in this section of the country. The only safeguard, under present conditions of improper farm management and land use, is to be found in adequate engineering developments. Cooperation of the entire valley resulted in the organization of the Miami conservancy district to provide for a method of flood control during high waters. The method finally chosen consisted in the construction of five great retaining basins in the valley. These basins are so constructed that during the highest floods only such amounts of water will escape as can be safely cared for by the river channel. The excess water accumulates back of the retaining dams and flows off after the flood waters have subsided.

HISTORICAL DEVELOPMENT

The history of this valley, like that of the Scioto, is one of land clearing and agricultural settlement, together with the development of manufacturing industries. Land ownership is largely in small tracts (10 to 150 acres). The Miami conservancy district owns several larger areas in the storage basins.

The number of acres owned in this district (the Miami Valley) in 1883 was 3,378,234. Of this 17.83 per cent was in woodland, 58.73 per cent was arable land, 17.96 per cent was in pasture, 5.48 per cent was lying waste.[3]

CONDITION OF LANDS OTHER THAN FOREST

The Miami Valley is one of the more important industrial regions of Ohio. This permits intensive development of the agricultural land. Corn, wheat, hay, and tobacco are the crops of principal importance. Dairy farms are extensive in the vicinity of Cincinnati, Dayton, and other cities. The climate and soils are favorable to crop production. Ninety per cent of the total land area is in farms, 56 per cent is cropped, 26.6 per cent is pastured, and about 9 per cent is woodland on the farms.

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[3] The First Annual Report of the Ohio State Forestry Bureau, 1885, p. 224.

CONDITION OF FOREST

The original forests of the Miami Valley were principally of beech and maple, with a number of associated species such as oak, hickories, black walnut, and white ash. On the poorly drained upland soils, especially in the northern part of the valley, many areas were covered by a swamp type of forest. This consisted principally of silver maple, American elm, bur oak, swamp white oak, white and black ash, and, in some areas, pin oak.

These forests were heavily cut during the period of land clearing for agriculture, the more valuable species being culled out. The woodland has been reduced in area by destructive cutting practices and land clearing, so that it is now confined to isolated tracts on the ridges, on the rougher part of the slopes, and in the wetter lowlands. On some of the worn-out farm lands, which have been badly eroded, a mixture of red cedar, sycamore, walnut, slippery elm, and sweet gum has become established. None of these species occupied an important place in the original forest. Red cedar is well adapted to reclaim denuded slopes where the soils are calcareous.

The isolation of wood lots in this valley makes them comparatively safe from fire. However, during both the spring and fall seasons, when the hardwood litter is dry, fires are very destructive, as they destroy not only all the small trees but wound the larger ones, paving the way for subsequent decay. Because of the shallow-rooted character of the beech, grazing, which has been very prevalent in the wood lots of this valley, has been very destructive among the older stands. Trampling by stock has wounded the roots of beech trees and opened the way to decay.

PROTECTIVE VALUE OF THE WATERSHED

The protective value of the watershed is summarized in the following tabulations:

SOIL

Square miles	Protective rating
4, 915	90
437	50

Weighted average for the watershed, 87.

TOPOGRAPHY

Square miles	Protective rating
1, 338	70
4, 014	85

Weighted average for the watershed, 81.

COVER

Square miles	Protective rating
447	50
2,999	60
1,425	76
481	90

Weighted average for the watershed, 66.

PRECIPITATION

The protective rating of this watershed with regard to the amount and distribution of precipitation has been given a scale value of 86. This rating is applicable in normal years but periodically this valley is subject to severe storms concentrated over a short interval.

Average rating of the basin

	Protecting rating
Soils	87
Topography	81
Precipitation	86
Cover	66
Average	80

CRITICAL AREAS

The flood menace in the headwaters of this valley has been reduced by the system of dams recently constructed. Since gully erosion is not bad in any but steep bluff lands, there is no reason, so far as concerns watershed protection, for forestation of any lands other than the bluffs, the ravines, and the basins of impounding reservoirs. Sheet erosion is, however, serious on all overgrazed pastures and from farm lands.

RECOMMENDATIONS

The original plan of the administrators of the Miami conservancy district was to forest a considerable proportion of the rougher lands in the areas held for water-storage purposes, and this plan should be carried out if possible. The plan was abandoned because of the cost and also because certain other types of cover checked the immediate erosion. Experiments should be carried out to determine the suitability of forest cover for the storage basins themselves, and following that cover planting should be continued. The only other lands in the Miami basin which should be retained in forest cover are the more severely eroded bluff lands and ravines. Private owners should be encouraged to restore all such lands to forest and to prevent grazing on those which now are forested.

An increase in the percentage of woodland on the farms of this valley would increase the value of the farms and the attractiveness of the valley, and such a program would doubtless receive good public support.

MONONGAHELA DRAINAGE AREA

(Area 12)

LOCATION

The source of the Ohio River is at the junction of the Monongahela and Allegheny Rivers, and the Monongahela flowing from the south is one of its more important tributaries.

The total area of the Monongahela drainage is 7,339 square miles, 4,214 of which lie in northeastern West Virginia, 2,718 in southwestern Pennsylvania, and the remainder of 407 square miles in northwestern Maryland.

The principal tributaries of the Monongahela are the Youghiogheny, Tygart, Cheat, and West Fork Rivers.

TOPOGRAPHY

The drainage basin has a maximum length of 140 miles. In width the maximum is about 80 miles at the West Virginia-Pennsylvania line.

The major portion of the Monongahela drainage lies in the Allegheny Plateau, a region much dissected and at present having the aspect of high rolling hills. None of the drainage area has been glaciated. Its eastern rim lies in the Allegheny Mountains, which also extend into the Allegheny River Basin. Only a very small portion of the watershed confined to alluvial flats along the streams may be classed as "plains." The approximate percentage of the area in each of the physiographic divisions is as follows:

	Per cent
Mountainous	23
Hills	66
Rolling	8
Plains	3

The elevation of the water surface at the head of the river is 4,100 feet; at the mouth of the river, 703 feet. The greatest land elevation is at the head of the Cheat River at about 4,800 feet. The entire eastern rim of the basin is high, having a mean elevation of 3,800 feet. The western rim is lower, having a mean elevation of 1,950 feet.

Slopes are steep in the eastern part of the drainage, but become more gradual toward the west. The general trend of the valley is northerly. The greater part of the drainage lies east of the main river, so that westerly exposures prevail. Hills are rounded and bear somewhat flattened tops where the major part of the farming is done.

From Fairmont, W. Va., to the mouth the velocity of the main river is not great. This part of the stream has been slack-watered by a series of transportation dams. The main tributaries flow through narrow, rugged, V-shaped valley with short steep grades and rocky beds.

The stream bed of the main river is composed of clay and sand. Bed rock outcrops in places. The channels of the tributaries are made up of rock strata in many places, especially in the upper stretches.

Swamps exist in the mountain sections of the Monongahela drainage and are known locally as "glades." About 16,000 acres in Garrett County, Md., is occupied by swamps. Swamp areas also exist in Randolph, Tucker, and Preston Counties, W. Va. Lakes exist only where they have been created artificially.

Twenty-two possible reservoir sites have been surveyed by the Pittsburgh Flood Commission. These lie in tributaries of the main river. The total capacity of the proposed reservoirs is 30,772,000,000 cubic feet. One large power dam has been built in Garrett County, Md., and others are projected.

GEOLOGY AND SOILS

With the exception of the eastern border, this basin lies entirely within the Allegheny Plateau. The underlying formations are of the Upper Carboniferous period (Pennsylvanian). Coarse sandstone and conglomerate (Pottsville) is the summit and ridge formation. Sandstone and shale interbedded with thin limestone (Monongahela and Conemaugh formations) are extensive in the northern portion of the basin. In the northwestern portion is a small area of shale, thin-bedded limestone, and fine sandstone (Dunkard formation ascribed to the Permian). The soils from the Dunkard formation are calcareous and are regarded as valuable for agriculture Brooks soil series). These soils are of medium depth and good drainage, and are not subject to serious erosion under judicious cultivation. Erosion and gullying, however, frequently occur on the steeper slopes.

The majority of the upland soils within the basin have been derived from sandstone and shale (DeKalb series). They are comparatively shallow and subject to rapid washing on exposed slopes. On many of the steep ridges the fine particles of the soil are removed as rapidly as they are formed.

CLIMATE

Data from climatological stations in this watershed, covering a period varying from 9 to 47 years, show the range in mean annual precipitation to be from 37.63 to 62.51 inches. The lowest and highest figures recorded for any one year were 19.14 inches and 80.86 inches. From 51 to 56.9 per cent of the precipitation occurred during the six warm months. Precipitation in northeastern West Virginia and northwestern Maryland is important from the standpoint of erosion and run-off. This region is subject to severe rain and heavy snowfall but the snow does not lie on the ridges for prolonged periods. Mean annual snowfall is highest at Pickens, W. Va. (101 inches) and lowest at Irwin, Pa. (24.7 inches). The mean annual temperature ranges from 47.5° to 53.6° F.

HISTORICAL DEVELOPMENT

Settlement in the lower Monongahela Valley began very early. The agricultural land in this basin was cleared so early that little record now exists of the original forest. This is true of about 50

per cent of the Monongahela drainage. The other 50 per cent was less suitable for farming and remained in forest until markets for lumber began to develop.

After the supply of timber was about exhausted in the Allegheny watershed, many of the large operators moved into the headwaters of the Monongahela. Some of these larger operations are still continuing in West Virginia.

Coal, oil, and gas have all been extensively developed in this valley. Along with the coal-mining industry should be mentioned the coke industry, which has centered about Connelsville, Pa. As a result of this industry, at least 125,000 acres of land are estimated to have been made barren in the past, in Westmoreland and Fayette Counties, Pa. This land now has a sparse covering of grass and weeds but supports no tree or brush growth.

Railroads built to remove the coal played a large part in removing the timber, although many of the streams were driven prior to the development of the railroads. Early development of the iron industry led to clear cutting of the accessible hardwoods to furnish charcoal. Land utilization, as shown by records of the agricultural census for 1925, is indicated below. The percentage of wild land and land in cities and roads has been derived by a process of elimination, all available information being used.

	Percentage of whole
Land in farms, cities, and roads	75.2
All other land—waste and wild	24.8
	100.0

In greater detail, the land status in the Monongahela Valley is as follows:

	Percentage of whole
Crop land	18.9
Pasture land	26.2
Woodland pasture	6.4
Woods not pastured	9.7
Waste land in farms	3.8
Wild land	24.8
Land in cities, roads, and railroads	10.2
	100.0

CONDITION OF LANDS OTHER THAN FOREST

Land actually cultivated occupies 18.9 per cent of the drainage area. The principal farm crops are corn, oats, wheat, hay, potatoes, apples, and peaches. Methods of cultivation designed to prevent erosion have been developed in some cases by individuals. As a rule, however, the steepest slopes are left in woods or pasture.

After heavy summer rains the streams of the region carry a large amount of silt, the result mainly of sheet erosion. Deep gullying is not conspicuous.

Pasture occupies a greater area than any other single class of cover. Generally pasture was developed by one method: The timber cover was "deadened" and crops planted; the land became too poor for crops; the dead timber was removed; the land was pastured, and eventually reached the present state of sod pasture. Gullying took place between the abandonment of the farm land and the establish-

ment of sod, but ceased after sod was established. The grass cover is capable of preventing gully erosion, but it can not prevent rapid run-off from heavy storms. Much of the pasture land reverts to woodland, especially where it is not heavily grazed and woodland adjoins.

The "glade" lands in Garrett and Preston Counties will probably never be in forest. They are grazed extensively in summer and occasionally burned under the erroneous impression that burning improves the grazing. These fires usually extend to surrounding wooded areas, thus making grazing an indirect cause of forest damage.

Brush lands which exist in the drainage basin usually consist of old fields or cut-over land in the process of restocking.

CONDITION OF FOREST

All of the wooded areas in the Monongahela watershed fall within two general types, namely, the spruce-hemlock type and the upland hardwood type. Bottom-land hardwoods exist to a very limited extent along the streams. Originally northern white pine occurred in some of the valleys, but this is no longer important as a type.

The spruce-hemlock type is found at the highest elevations except where soil is lacking. The hemlock increases at the lower limits. At the highest elevation, the type is practically pure spruce.

The upland hardwood type consists of a great variety of species. Hemlock occurs generally through it, being most abundant on the north slopes and in the coves. The most abundant hardwood species in the mixture are yellow birch, sugar maple, beech, cherry, various oaks, hickory, basswood, yellow poplar, and formerly some chestnut.

About 400 square miles of the total Monongahela drainage is within the spruce-hemlock type, and 2,100 square miles is the approximate area of the hardwood type.

Logging on spruce and hemlock lands required a considerable investment, and the narrow margin of profit led to the cutting of all merchantable material, even pulpwood. Where fire was kept out, advance growth of spruce and hemlock partially restocked the land. Slash and bushes kept the ground covered except in the skid trails where some erosion of soil occurred for several years.

Logging in the hardwood type has been more widespread. Saw timber, poles, ties, and mine timbers have all been cut in varying degrees of intensity. The present stands at best are badly culled; some areas have been clear cut.

In both types, slash is left as it falls or is roughly windrowed for ease in skidding. In the hardwood type reproduction from sprouts is prompt, and this, together with such established seedlings as are left after logging, tends quickly to restock the soil.

Rarely does either type escape fire after logging. In the spruce type the fire which follows logging kills all standing spruce and hemlock. On the highest ridges, where the soil is thin, the soil itself is removed by the fire. These ridges are either devastated and not restocked or are so badly burned that only inferior species such as aspen and wild red cherry can grow for a long period.

In the hardwood type fire may kill all standing trees, but sprouts are assured except after exceedingly hot fires, which burn the humus.

The soil is usually deeper than that under the spruce type and total devastation is not common, unless through repeated fires. Grazing is usually confined to the glades within the forest areas, so that damage is chiefly to the better species such as yellow poplar.

In general only about 1 per cent of the original virgin forest remains in the Monongahela watershed. Practically all of the cut-over areas have been burned but are becoming restocked. The spruce type includes 19 per cent of the forested area and the remaining 81 per cent is in the upland hardwood type. Totally devastated areas are confined to the highest elevations and are not extensive. Areas devastated by the coke industry, although not forested, have enough vegetation on them to prevent serious erosion.

PROTECTIVE VALUE OF THE WATERSHED

SOILS

The protective rating of 75 assigned to this basin, on the basis of its soils, was obtained through consideration of its several soil types. Those on the upland derived from sandstone and shale are least subject to erosion unless exposed on steep slopes. They were rated at 80, while the soils of the Dunkard and Monongahela formations were rated at 60.

TOPOGRAPHY

High altitudes, steep slopes, and the prevailing westerly drainage have all been considered in the rating of topography at 58 as shown:

Square miles	Protective rating
5, 351	50
1, 623	75
365	100

Weighted average, 58.

PRECIPITATION

Over an area extending from the headwaters of the Buckhannon River in West Virginia northeast to the northern rim of the watershed the mean annual precipitation is in excess of 50 inches. This area includes the highest land in the Monongahela drainage basin, and consequently the steepest slopes and greatest ranges in elevation. Considering the distribution and intensity of rainfall, the protective value of the watershed may be rated at 67 per cent.

COVER

Protective rating based on character of cover has been determined with regard to the area in improved and unimproved land.

Square miles	Protective rating
2, 055	50
2, 642	75
2, 642	100

Weighted average, 77.

Average rating for the basin

	Protective rating
Soils	75
Topography	58
Precipitation	67
Cover	77
Average	69

The condition of this watershed in respect to run-off and erosion is shown by the relative factor of 69 obtained by averaging the four values previously obtained. The critical condition found in respect to soils, precipitation, and topography is only slightly relieved by the forest cover, which is of unsatisfactory character.

CRITICAL AREAS

The clearing of forest from the hilly land over the greater part of this watershed has increased erosion and run-off. Two distinct areas are indicated as critical. The eastern rim of the drainage area receives greater rainfall and has lower temperatures, steeper slopes, greater elevations, and more devastated land. The only controllable factor within this area is the cover, the present condition of which has been outlined above. The other critical area lies in Fayette and Westmoreland Counties, Pa., comprising that region mentioned above as damaged by the operation of the coke industry.

RECOMMENDATIONS

About 40 per cent (2,900 square miles) of this basin should be retained in forest cover. This should include all nonagricultural land which is liable to severe erosion or rapid run-off. The restoration of forest cover should give way to other uses of such land only where forestation is decidedly uneconomical. This applies especially to the land injured by coke-oven gases.

MUSKINGUM DRAINAGE AREA

(Area 13)

LOCATION AND AREA

The Muskingum River drains the east central part of Ohio, flowing south to the Ohio River at Marietta, Ohio. Though the general trend is southward, the course about midway of the valley is westerly for about 40 miles. The valley is nearly as broad as it is long and has an area of 8,052 square miles.

TOPOGRAPHY

The tributaries entering the valley from the north and west sides of the valley all head in regions of glacial drift, which on the southern margin of the glaciated region amounts to deep morainal deposits. The lower part of the drainage basin is unglaciated and the topography is hilly to rough. Here the streams run through deep valleys cut in bedrock.

The general elevation is between 1,000 and 1,100 feet above sea level, ranging from about 600 feet along the lower portions of the Ohio and Muskingum Valleys to nearly 1,400 feet at Bangorville, in the northwestern corner.

The Muskingum River, 125 miles in length, is formed by the junction of the Walhonding and Tuscarawas at Coshocton. It is 211 miles, measured along the stream, from the mouth of the Muskingum to the headwaters of the Tuscarawas. Other large tributaries are the Licking and the Wills Rivers. Killbuck Creek enters the Walhonding just above its junction with the Tuscarawas. The Muskingum is made navigable as far as Zanesville, a distance of 70 miles, by means of 10 locks.

The gradient per mile from the Ohio River to Zanesville is only 1.5 feet, and from Zanesville to Coshocton 2.6 feet. The water is comparatively sluggish in the Tuscarawas and in the lower part of the other streams also, but the flow is much more rapid in the upper part of all the branches. The rate of fall on the Wills River is 4.5 feet per mile, on the Walhonding, 6.9 feet, and on the Licking 9.5 feet.

At one time there were many water-power developments on the small streams and the upper parts of the larger rivers in the Muskingum Basin. In many places the backwater of one lock reaches to the tailrace of the one above. However, in later years, the silting up of the ponds and the decline of water transportation have operated to reduce the number of power developments kept in use. A new period of power-site development is now under way.

Floods are frequent in the smaller streams of this watershed because of the hilly character of the country. The water rises rapidly in the main river, but reaches the flood stage about once a year, on an average, at Zanesville.

This basin contains practically no large swamps or natural reservoirs. Buckeye Lake, about 10 miles south of Newark, was artificially developed in the basin of a natural swamp.

GEOLOGY AND SOILS

The western part of this basin is underlain with limestone, sandstone, and shale (Waverly and Maxville formations of the lower Mississippian). The central part of the basin is underlain with sandstone and shale of the Pottsville and Allegheny groups of the Pennsylvanian system. Three principal formations, also of the Upper Carboniferous, are present in the eastern portion of the basin (Conemaugh, Monongahela, and Dunkard). These are made up of rather thin bedded sandstone, shales, and limestone.

The northwestern third of the basin has been glaciated, and gravel plains and lines of glacial drainage have been well established. The topography is rolling. The glacial soils are chiefly silt loam. They are derived from the weathered surface of glacial drift from sandstone, limestone, and shale (Wooster soil series, chiefly). The drift over the northern portion of the glaciated belt is derived from sandstone and shale without limestone. The soils are silt loam that often develops faulty drainage on cultivation (Volusia soil series).

The soils of the unglaciated central portion of the basin are silt loams and fine sandy loams from sandstone and shale (Muskingum

FIGURE 2.—Erosion on a hillside of moderate slope. A sod cover is unable to hold the soil. Duck Creek, Washington County, Ohio

334—1

FIGURE 3.—Extreme erosion of loess soil in the Ozark hill region of southern Illinois

334—2

(Dekalb) soil series). They are of medium depth and fairly well drained. Washing is not generally serious.

In the southeastern part of the basin the soils are chiefly clay loams from thin sandstone shale (Meigs soil series). Gullying and washing are common, and landslips are frequent. Severe gullying occurs, especially on abandoned farms and mine properties on some of the steeper slopes in the southern portion of the valley and more particularly in Washington County. Soils are severely eroded from many pastures and old cultivated fields.

CLIMATE

Climatological stations in this drainage area have records covering from 6 to 102 years, which show a variation in mean annual precipitation between 33.04 and 42.39 inches and a range from minimum to maximum precipitation from 22.55 to 62.79 inches. About 55 per cent of the rainfall occurs during the six warm months, with a concentration during June, July, and August. Records for excessive 24-hour rainfall show a region of outstanding importance in the neighborhood of Cambridge, Gratiot, and Zanesville, Ohio. In all cases the excessive precipitation in this upper section came during the summer season (June, July, and August). Snowfall increases in intensity and is of more importance in the headwaters, a range for the whole drainage reaching from about 20 to 36 inches. Mean annual temperatures vary from 49.1 to 54.2° F.

HISTORICAL DEVELOPMENT

Marietta, at the confluence of the Muskingum and Ohio Rivers, was settled in 1788. Settlers migrated rapidly up the valley. Zanesville, the principal town on the lower valley, was founded in 1799. Clearing of land for cultivation rapidly followed the settlement. Coal mining is an important industry in the lower part of the valley. Oil and gas wells are also abundant.

The following table indicates the present utilization of land:

	Per cent
Farms:	
Crop land	38.0
Pasture	39.0
Woodland not pastured	5.7
Pastured woodland	6.7
Unclassified	10.6
Total	100.0

The last item includes areas of land not developed as farms ("wild land"), also cities, villages, roads, and railroad rights of way.

CONDITION OF LANDS OTHER THAN FOREST

Thirty-eight per cent of the total area of the basin is crop land; 39 per cent has been pastured. The principal farm crops are corn, wheat, oats, and hay. Orchards are important in certain sections. Dairy farming is practiced more or less extensively throughout the area, but especially at the northern edge of the drainage basin. Erosion is reported in Washington County.

CONDITION OF FOREST

The original forest was composed almost entirely of hardwoods. Scattered stands of northern white pine and hemlock in the northern and scrub pine with some short-leaf pine in the southern part of the region were of minor importance. The virgin forest in the lower basin was principally a mixed hardwood type, consisting of oaks, yellow poplar, chestnut, hickories, and other species, with beech and maple along the streams. The northern end of the valley had beech and maple prevalent on morainal lands with the remainder of the forest of oak-hickory and elm-ash types.

None of the virgin forest in this basin remains. About 15 per cent of the area, nearly all of which is included within the fences of the farms, is still forested. The region has been successively logged for saw timber and for railroad ties, and, in the vicinity of the mines, for smaller material for mine ties. The cut over forest land which was not plowed and used for farming quickly produced a second growth stand of sprout and seedling hardwoods. This is the type of timber which, more or less culled over for ties and pulpwood, constitutes the remaining forest of the region. Some abandoned fields have reseeded to yellow poplar, black locust, and other hardwood species, so that they promise to return quickly to a forested condition. Logging is now done entirely to supply portable mills.

Forest fires are not important in this area. The isolated condition of many of the wood lots would prevent their spread if started. None of the area within the Muskingum drainage basin has been included in the territory organized by the State for protection from fire. Grazing of the wood lots is prevalent practice. This opens up the woods through destruction of all new growth within reach of the cattle. Under heavy grazing the forest eventually attains a park-like appearance.

PROTECTIVE VALUE OF THE WATERSHED

The protective rating of the watershed is summarized in the following tabulations:

SOIL

Square miles	Protective rating
3,687	90
3,250	80
1,115	60

Weighted average for the watershed, 82.

TOPOGRAPHY

Square miles	Protective rating
5,152	75
2,900	90

Weighted average for the watershed, 80.

COVER

Square miles	Protective rating
652	50
3,057	60
3,137	75
1,206	90

Weighted average for the watershed, 69.5.

PRECIPITATION

The protective value of this watershed with regard to the amount and distribution of precipitation has been given a scale rating of 91.

Average rating for the basin

	Protective rating
Soil	82
Topography	80
Precipitation	91
Cover	69.5
Average	80.6

CRITICAL AREAS

The rapidity of run-off has undoubtedly been increased in this drainage area through the clearing of timber, but the favorable condition of soil, the topography, and character of the precipitation have prevented erosion in the Muskingum Valley from being severe. The general tendency has been to clear the tops of the ridges and more favorable valley lands, leaving wood lots along the slopes. Clearing of land has undoubtedly progressed further than can be justified if further erosion is to be controlled, but the limited forest cover will continue to be located in the ravines and on the steeper bluff lands along the streams. These will be isolated areas of woodlots included within the farms. The most serious condition of erosion exists in the lower quarter of the drainage area where the soils are clay loams of the Meigs and Westmoreland series. These soils are quite devoid of calcareous material and when exposed in pasture fields are unable to support a continuous cover of blue grass without lime and phosphate treatment. Breaks in the cover usually result in the beginning of serious erosion on the steeper slopes.

RECOMMENDATIONS

Except in the northwest section on the headwaters of the Mohican River, this valley has no areas suitable for acquisition as public forests. Improvement of the forest conditions should be accomplished by educational measures, supported by distribution of planting stock.

Grazing should be controlled in the wood lots to allow them to regenerate when cut over. Underplanting and improvement cuttings should be practiced to improve the character of the wood lots. When-

ever crops have been cultivated on steep lands to the point of starting erosion such lands should be salvaged by forest plantations. Adequate protection from fire should be extended over this region to include all territory where privately owned woodlands are joined in contiguous blocks.

OHIO RIVER (DIRECT)

(Area 14)

LOCATION

In addition to the principal tributaries listed and described separately, the Ohio River is fed by a number of short rivers and creeks. The most important among these are the Tradewater, Little Kentucky, and Little Sandy Rivers in Kentucky; the Little Muskingum, Hocking, and Little Miami Rivers in Ohio; the Blue River in Indiana; and the Saline and Cache Rivers in Illinois. These rivers and a large number of creeks drain an area of 26,239 square miles lying in an irregular strip 40 to 60 miles wide along the Ohio. This area is comparable in size to the drainage area of the Wabash River with all tributaries.

TOPOGRAPHY

The Ohio River flows from the junction of the Allegheny and Monongahela at Pittsburgh to the mouth of the Cumberland River largely through a sunken channel which it has cut in the plateau. The height of the bluffs along the Ohio Valley varies from 100 to about 250 feet. In some instances the bluffs approach the river closely and in others are separated from it by areas of flat bottom land. The average width of the gorge of the Ohio is from 1½ to 3 miles, although in some places in the bends of the river, a much wider alluvial plain is formed. The broad bottoms of the Ohio are chiefly located in the lower portion along the southern end of Illinois.

In some places the bluffs are precipitous, and in others they take the form of steep rolling hills deeply cut by all of the tributary drainage. There is no flat land in this subdivision except the bottom lands of the Ohio itself and of some of the tributary streams. With the exception of 6 or 7 per cent of bottom land, the whole basin may all be classified as hilly. No mountains come directly to the Ohio River.

GEOLOGY AND SOILS

For convenience of discussion, the areas which drain to the Ohio River (direct) have been separated into five divisions based on geographical position.

(1) Southern Illinois and associated areas in westernmost Kentucky.

(2) Southern Indiana and associated areas in Kentucky.

(3) Southwestern Ohio (Little Miami River Basin) and the areas of Kentucky lying south and west of this.

(4) Hocking River Basin of Ohio and associated areas, including the adjacent plateau area of Kentucky.

(5) The panhandle area of West Virginia and associated areas.

(1) *Southern Illinois and associated areas in westernmost Kentucky.*—The upper portion of this area lies in Illinois as an extension of the western coal fields of Kentucky. It is underlain with sandstone, shale, and coal of the Pennsylvania age. The portion lying north of the Ozark Ridge has been glaciated and bears a mantle of Illinoian drift.[1] This comprises about 40 per cent of this area in southern Illinois. The soils are silt and sandy loams from weathered glacial drift. They are rather poor in quality and are subject to washing under continued injudicious cultivation.

Stretching across the middle of the area from west to east is an extension of the Ozark Plateau known as the Ozark Ridge. This plateau has rough and hilly topography, and the southern slope declines more rapidly than the northern slope. Gorges have formed where the hard sandstone cap has been worn through, exposing the underlying formations of softer limestone and shale (St. Louis and Chester groups) of Mississippian age. "The rock capping of nearly all of the hills is formed by sandstones or conglomerates, the latter being most common in the northeastern part. These sandstones and conglomerates are hard siliceous rocks which weather very slowly."[2] These particular strata belong to the Pottsville formation of the Pennsylvanian. The soils of this plateau are of loessal origin, sandy and clayey loams of medium depth and fair drainage. On the steeper slopes, clearing of the land has resulted in severe washing and gullying, and injudicious cultivation has led to the same result on even less hilly land.

"Upon many of the more eroded places the soil has been almost or entirely removed * * *. The soil washes very easily, and wherever a gully is begun the water cuts rapidly down through the unresisting loess."[3] Pasture and orchards make up a considerable portion of cleared land at present.

The southern portion of the area in Illinois is underlain with limestone and shale of Mississippian age. It has not been glaciated, yet its surface has been influenced by glacial material from the north that has been reworked by wind and water. It is largely from this material that the soils have been derived. Bluffs face the Ohio River, but the country lying between the Ozark Plateau and these higher lands along the river is swampy. Large areas have been systematically drained by open ditches. On the higher land the soils are clayey or silt loams, and where the land is sloping the soils are subject to washing when carelessly cultivated.

A small portion of the purchase area [4] in Kentucky drains to the Ohio direct. The underlying formations are sands and clays of comparatively recent geologic deposition. Recent alluvium occurs in the river bottom lands. The upland surface of this area has been influenced by glacial material that has been reworked by wind and water. The soils are silt loams of medium depth. As a result of careless cultivation, they have washed and gullied to a considerable extent.

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[1] Illinois State Geol. Survey Bul. No. 43, p. 280.

[2] U. S. Bureau of Soils. Soil survey of Johnson County, Ill., p. 725.

[3] Soil Survey of Johnson County, Ill., p. 726–27. U. S. Bureau of Soils.

[4] That portion of the State lying west of the Cumberland River was purchased from the Indians in the treaty of 1819, and from that receives its name.

Another area of Kentucky lying just north of the mouth of the Cumberland River also drains into the Ohio direct. The underlying formations in the southern portion are those of the limestone upland of western Kentucky, chiefly St. Louis limestone of the Upper Mississippian. The upper portion of this area falls within the western coal fields of Kentucky. Sandstones and shales make up the underlying formations. However, the underlying formations have not greatly influenced the soils of this area. Most of the area has been covered with glacial material from the north that has been reworked by wind and water. This surface layer is generally considered to be of loessal deposition. It is of a homogeneous silty character. The soils derived from this material are of loose, light texture, being of a silt loam type. Consequently, these soils are subject to severe gullying and washing when continuously cultivated.

(2) *Southern Indiana and associated areas in Kentucky.*—The belt running across the entire southern portion of Indiana drains to the Ohio direct. The youngest underlying formations are to the west, beginning with Pennsylvanian sandstone and the shale and proceeding eastward through narrow belts of Mississippian limestone, shale, and sandstone, Devonian shale and limestone, Silurian limestone, and ending on the eastern side of the state with Ordovician limestone. The underlying formations have not influenced greatly the surface mantle of soil cover. The eastern third of the area has been glaciated and is covered by a layer of glacial drift. The remainder of the area with the exception of a small portion in south central Indiana is covered by a mantle of glacial material thought to have been derived from drift material reworked and carried southward by wind and water.

Except where actual outcrops occur, the soils have been derived from the mantle or silty glacial material. They are sometimes deep and subject to severe gullying when carelessly cultivated on slopes.

In Kentucky, south of the central part of the Indiana boundary, is a region similar to the one just described. Its underlying formations are chiefly limestone, sandstone, and shale of the Mississippian system. A narrow belt adjoining the Ohio River is covered with a thin mantle of glacial loess. The soils derived from this are silty, fairly loose textured, and easily gullied. South of the belt, the soils are residual silt and clay loams. Under careless cultivation, washing and gullying frequently occur.

The areas in Kentucky lying between the mouth of the Salt River and the mouth of Licking River are underlain chiefly with limestone formations. A part of these areas has been glaciated. Most of the remainder has been covered with a mantle of glacial material, reworked by wind and water. The soils are loose silt loam types and will gully badly when carelessly worked.

(3) *Southwestern Ohio* (*Little Miami River basin*) *and the areas of Kentucky lying south and west of this.*—Most of this area is underlain with limestone formations. The area in Ohio has been glaciated with the exception of the southeastern portion, and the weathering of the glacial till plains has given rise to the surface soil layers. In Adams County, and parts of Brown and Highland Counties is a small area of residual limestone soil. The soils are generally silt loams, subject to considerable destructive washing in

the southern portion near the Ohio River, where the topography is hilly.

In the remainder of Brown, Clermont, Highland, and parts of Warren and Clinton Counties the soils are loessal in origin and are underlain with limestone. The region is, with a few exceptional areas, level to rolling. The exceptions occur along the streams, particularly along the East Fork of the Little Miami, where a deep gorge has been cut into the limestone. Areas such as these, bluff lands along the streams need the protection of a good forest cover.

The southeastern portion is of very rough topography. The underlying formations are Devonian limestone, sandstone, and shales of the lower Mississippian. The soils are shallow and are subject to erosion on steep slopes. The Kentucky area, southward, is of the same geologic nature. The western portion of the Kentucky area is underlain with limestone. The soils are residual loams. Under careless management, they have suffered from destructive erosion along the river bluffs.

(4) *Hocking River basin of Ohio and associated areas, including the adjacent plateau area of Kentucky.*—The Hocking River basin lies in the western border of the Appalachian plateau region in southeastern Ohio. The underlying formations are chiefly of sandstone and shale, with some thin bedded limestone. The area is of rough topography. Sandstone outcrops are commonly present.

The principal soils of the western two thirds of the area belong to the DeKalb series and are derived from sandstone formations. They are generally shallow on steep slopes and have suffered from erosion when cleared and cultivated. The predominant soils of the eastern third of the basin along the Ohio River are of the Meigs series from sandstone and red shales. They are of medium depth and fair drainage. These soils are subject to gullying, and on steep slopes they are subject to landslips and landslides.

The small area lying eastward across the Ohio River in West Virginia and draining to the Ohio direct is of the same general nature.

The area in Kentucky, lying southwest of the Hocking Basin and draining into the Ohio, is in the border of the Appalachian Plateau. It has a very rough topography. The soils are from sandstone and shale, and are subject to severe erosion when exposed, particularly along the hilly areas facing the river.

(5) *The panhandle area of West Virginia and associated areas.*—In northwestern West Virginia, southwestern Pennsylvania, and eastern Ohio a considerable area drains to the Ohio directly by small streams. This area includes the panhandle of West Virginia and contiguous areas. The entire area is within the Appalachian Plateau province. The underlying formations are sandstone, shales, thin limestone, and coal of Upper Pennsylvanian and Permian age.

The northern portion of the area has a greater abundance of sandstone, and the soils are chiefly of the De Kalb series, medium to shallow, and washing badly when exposed on steep slopes.

The southern portion of the area has developed two important soil series—the Brooke soil from thin limestone, shale, and fine sandstone, and the Meigs series from sandstone and red shales. The latter are subject to extensive gullying and show evidence of land-

slips and landslides on steep slopes. The former are good agricultural lands because of their limestone nature. They are not found in particularly rough areas but where they do occur on slopes the Brooke soils will wash considerably.

CLIMATE

From Pittsburgh, Pa., the precipitation increases in amount toward the mouth of the Ohio at Cairo, Ill. The mean annual precipitation has been found to range from 32.76 to 52.55 inches, according to data from stations in this drainage covering 5 to 86 years. Minimum and maximum records of rainfall have been established at approximately 18 and 97 inches. Areas of relatively high precipitation along the Ohio are found in southern Ohio, northern West Virginia, and northern Kentucky. Southern Illinois and Indiana are regions of medium heavy rainfall, so that practically all the land adjacent to the Ohio River has rather high precipitation. From about 47 to 59 per cent of the rainfall for the year occurs during the six warm months (April to September).

There is a gradual increase in snowfall toward the head of this drainage basin. Mean annual snowfall varies from about 15.8 to 45.4 inches. Data for excessive 24-hour rainfall give Evansville, Ind., the highest record, 6.94 inches, and show an area in southeastern and southern Ohio which is important. From 48 to 57.8° F. covers the range in mean annual temperatures for this part of the Ohio drainage basin.

HISTORICAL DEVELOPMENT

The first settlement in the basin was at Vincennes on the Wabash by the French in the middle of the eighteenth century. The English Zane brothers settled first at Wheeling in 1770. Although this and other settlements, notably the one at Louisville, were made prior to the Revolution, it was not until 1778, when George Rogers Clark made his successful foray into the Indian country, that settlement really started in earnest. It was not long before other groups of men were induced by the excellent opportunity to settle in the valley.

> A clear title to 400 acres of well-watered and well-timbered, productive land, in an agreeable climate, where game was abundant, could be obtained by simply putting up a log cabin and raising one crop.[1]

From the close of the War of 1812 to 1836 was a period of active settlement. At the time of the completion of the canal around the falls of the Ohio, in 1830, all of the rich alluvial bottom lands along the Ohio River were well cleared for agriculture.

Prior to 1830 the utilization of the timber along the river was confined to supplying local demand and material for ship and barge building to take care of the increasing need for transportation due to the production of coal and iron in the Alleghenies up the river. Extensive rafting and floating of the better timber species began about this date, but it was not until about 1870, with the advent of the railroad and the band mill, that extensive exploitation of the timber resources was started. Logging by 1890 had moved back into the more remote districts, and the lumber industry close to the Ohio

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[1] The Picturesque Ohio, by C. M. Clark.

ceased to be of importance. At the present time the forested areas are chiefly confined to farm woodlots and to certain bottomlands in the lower reaches of some of the tributaries. The iron industry, which started about 1790 near Pittsburgh, developed the charcoal industry along the river. This industry reached its peak in the seventies.

Coal mining has been of considerable importance, particularly in the northeastern end of the drainage, since about 1820.

Ownership along the Ohio is largely confined to small farms of 160 acres or less.

The present status of land utilization for this section of the Ohio Basin is found in the following table, derived in part from the 1925 Census of Agriculture:

	Per cent
Farm lands:	
Crop land	34.0
Woodland pasture	6.2
Other pasture	27.2
Woodland not pastured	8.2
Waste land in farms	6.4
Total	82.0
Other lands:	
Wild land	7.8
Cities, towns, rights of way, etc	10.2
Total	18.0
Total forest land	22.2

CONDITION OF LANDS OTHER THAN FOREST

Practically all of the flat bench land along the Ohio River has been cleared for agriculture and is considered extremely valuable. Even the sloping banks extending down to the river have been cleared and are used for this purpose. This also applies to the lower reaches of the shorter tributary streams. Corn, grains, and garden truck are raised on this land. Where the danger of washing is too great the land is retained in pasture. Bank erosion on the Ohio itself is not important, since the valuable alluvial land has been protected by levees. Throughout most of its length the Ohio is bordered by steep bluffs on both sides, sometimes separated from the river by several miles of flat land. These bluffs are commonly pastured or covered with an inferior growth of timber. This is also true of the steeper ravines cut in these bluffs. Even near such cities as Cincinnati the steep land is protected by timber, but on the whole too much of the bluff land has been cleared. Erosion and landslips are frequent in some places, even disturbing the roadbed in the main highways along streams. In the valleys of smaller tributaries, such as the Little Miami and Hocking, the land is rougher than in the valleys of the longer streams, since the gradient is steeper.

This rough hill land has been cultivated wherever the topography would permit. Many farms, especially in the Hocking River Valley, have been abandoned because of the soil erosion. From the point of southern Ohio to Pittsburgh the soil is of sandstone and shale origin, unglaciated, and consequently when washed becomes too poor for

agriculture. In the vicinity of Wheeling, W. Va., the steeper fields were made unproductive early. Some of these recovered when turned into sheep pasture. The present tendency is to leave the steeper land in pasture. Toward the mouth of the Ohio a large area of flat land, once occupied by a lowland hardwood type of timber, is now in cultivation. This has been drained as well as possible and is protected by levees.

In general the land immediately adjacent to the Ohio River, with the exception of the flat stream bottoms and benches, is steep and too rough for cultivation. This applies to all except the higher lands, well back from the river, where the plateau has not been so severely dissected.

Although the Ohio State Agricultural Experiment Station recommends the use of lime and phosphate to improve the productivity of pasture land, it also recommends that the steeper land be left in forest cover. The State of Ohio has already purchased State forests in the southern counties adjoining the river.

CONDITION OF FOREST

There is only a small acreage of virgin forest in this division of the Ohio Valley. Almost all of the timber lands have been either cut clear or heavily culled. They have been uniformly subjected to grazing and have suffered severely from fire. Fire damage still continues, being more severe on the south than on the north side of the river.

The timber is chiefly upland hardwood with some scrub, pitch, and shortleaf pine on the south exposures; oak, hickory, chestnut, beech, and maple make up the bulk of it. On the flat land along the river bottoms, sycamore, willow, sweet gum, black gum, cottonwood, red maple, river birch, elm, and some yellow poplar are the tree species. Toward the mouth of the Ohio the southern type of forest is found, including cypress. Wherever it is possible to drain the land this lowland type has been cleared. The forest reproduces itself very well if not grazed, either in the lowland or upland. Most of it is grazed, has been materially reduced in density, and does not offer a good protection against run-off. The litter on the forest floor is very thin.

PROTECTIVE VALUE OF THE WATERSHED

SOILS

Square miles	Protective rating
1,312	90
4,198	80
2,099	70
6,560	60
12,070	50

Weighted average, 61.

TOPOGRAPHY

Square miles	Protective rating
19, 154	70
5, 248	90
1, 837	95

Weighted average, 76.

PRECIPITATION

	Per cent of area
Distribution:	
Good	60
Medium	20
Poor	20

General average of precipitation, 42.5 inches.
Protective rating: Weighted average, 83.

COVER

	Per cent of area	Protective rating
Crop land	34	60
Pasture	33	75
Forest	16	90
Improvements	17	55

Weighted average, 70.

For the purpose of rating cover all woodland pastures have been considered as pasture, as they are usually of such open character that they more nearly approach the condition of pasture lands.

Average rating for the entire drainage

	Protective rating
Soils	61
Physiography	76
Precipitation	83
Cover	70
Average	72. 5

CRITICAL AREAS

The bluff lands of the Ohio River and its immediate tributaries are generally suited for a forest cover. This applies also to the steeper hill lands on all the shorter tributaries of the Ohio. In most instances, however, this land is owned in small tracts and does not offer satisfactory units for acquisition by the State or Federal Government. In southern Indiana, southern Illinois, and southern Ohio, are several areas partially tributary to the Ohio direct which are large enough for State acquisition. Ohio and Indiana have already purchased tracts for State forest and park purposes. In West Vir-

ginia the opportunity for State purchase near the river is not as good as farther east in the river plateau section. This is also true in Kentucky. However, in addition to those areas designated by map, the bluff lands and river hill lands owned within the farms must be considered as critical areas.

RECOMMENDATIONS

1. Acquisition of State-owned forests in Illinois, Indiana, and Ohio.
2. Further protection may be afforded through the acquisition of municipal forests, as in the case of Cincinnati.

STATEMENT ON PRECIPITATION

The following table shows that the lower one goes on the Ohio River; the more severe are occasional storms. The greater 24-hour precipitation creates a possibility for greater run-off, greater volume of flowing water, and greater likelihood for erosion; and emphasizes the importance of a forest cover to bind the soil on bluffs, slopes, and areas susceptible of erosion. The stations are arranged in order from Pittsburgh, Pa., to Cairo, Ill.

Greatest 24-hour rainfall on and near the Ohio River from Pittsburgh to Cairo—Record to 1920

[Taken from Bulletin W, U. S. Weather Bureau]

State	Station	Greatest rainfall in 24-hour period	State	Station	Greatest rainfall in 24-hour period
		Inches			*Inches*
Pennsylvania	Claysville	3.15	Ohio	Green	3.66
Do	Aleppo	2.66	Do	Waynesville	4.38
Ohio	Milport	3.50	Do	Camp Dennison	5.10
Do	Demos	4.80	Do	Cincinnati	5.22
Do	Clarington	4.25	Kentucky	Anchorage	4.75
Do	Marietta	4.31	Do	Louisville	5.50
Do	Lancaster	3.46	Do	Irvington	5.07
Do	Amesville	3.19	Do	Owensville	5.31
Do	Ironton	4.12	Indiana	Evansville	6.94
Do	Portsmouth	3.52	Kentucky	Paducah	5.08
Kentucky	Maysville	4.68	Illinois	Cairo	5.69

SALT RIVER DRAINAGE AREA

(Area 15)

LOCATION AND AREA

The Salt River drains a triangular-shaped watershed in north central Kentucky between the valleys of the Kentucky and Green Rivers. A broad side of the basin parallels the drainage of the Ohio direct. The general course of the main river is westerly. The principal tributary from the northeast is Floyds Fork; from the southeast, Rolling Fork. The latter drains nearly half of the 2,986 square miles comprising the Salt River Basin.

TOPOGRAPHY

The northeastern section of this drainage lies in the blue-grass region of central Kentucky, an area characterized by more or less rolling topography. The southwestern part of the drainage as a whole is very rough and hilly, the valleys are narrow, and the slopes steep. The only part of the drainage that could be considered level land or plains is in the bottoms along the streams. The area may be classified with regard to topography about as follows: Hilly, 70 per cent; rolling, 28 per cent; plains, 2 per cent.

The stream elevation at West Point, the river mouth, is 380 feet, while at Danville, near the headwaters of Salt River, the elevation is 989 feet. The changes in topography are abrupt and the ridges rise from 200 to 300 feet above the streams; 35 to 40 per cent slopes are common.

The stream banks are steep and the stream beds are gravelly and rocky. There are many shoals, and in general the streams are swift. A dam on the Ohio River just below the mouth of Salt River makes the current sluggish for the last few miles of its course. The flow in the tributaries is variable, often changing from extreme high water during the winter and spring to almost dry channels in the summer. This is partly due to the fact that there are very few springs in the valleys. Formerly the Salt River was extensively used for navigation, but during the past 10 years it has not been used to any extent for this purpose. There are no lakes, and the amount of swamp land is negligible.

GEOLOGY AND SOILS

The western portion of this basin is underlain by formations of three geologic periods. These are limestone and shale of the Silurian period, cherty limestone and black shale of the Devonian period, and sandstone and limestone of the lower Mississippian. This region shows an irregular topography, brought about by uneven weathering of the different rock formations, and includes an area of rough country commonly known as the Knobs of Kentucky. The soils are thin silt loams of low fertility, often quite stony, and subject to gullying and washing when exposed.

The alluvial lands above the main stream beds are extensively cultivated. They are frequently flooded and a thin surface of silt is deposited over the area at such times, insuring the continued high fertility of the soils for agricultural use.

Two distinct types of topography are found about the headwaters of the Salt River and Beech Fork of the Salt River. These drain the western portion of the blue grass region. The rolling land with underlying limestone rock is largely agricultural, while the very hilly lands of the Edenshale belt have many areas of forest and abandoned fields. Erosion is most severe in the shale sections.

CLIMATE

The mean annual precipitation over the Salt River Basin is 44.94 inches with 49.8 per cent occurring during the warm season (April to September). The range in mean annual precipitation varies from

43.26 inches at Anchorage to 46.59 inches at Taylorsville. The maximum precipitation recorded for any one year occurred at Bardstown and amounted to 61.22 inches. The minimum recorded was 30.21 inches at Loretto.

The recorded mean annual snowfall is only 17 inches. Snow melts rapidly, rarely remaining on the ground for more than two or three days, and consequently plays a small part in winter and spring floods. The mean annual temperature ranges from 55.3° F. to 57° F. Local floods are usually the direct result of protracted rains during the fall, which completely saturate the ground, followed by winter rains when the ground is frozen, resulting in rapid run-off.

HISTORICAL DEVELOPMENT

The Salt River Basin was settled soon after the Revolutionary War and the clearing of land for agricultural purposes began at that time. Toward the end of the nineteenth century, lumbering assumed an important rôle in Kentucky and the forest on the larger part of this drainage has been repeatedly culled to supply local demand and for export.

The ownership is confined to small tracts, the average sized farm being about 80 acres. There is one exception to this, that being the Camp Knox Military Reservation of 33,000 acres located in Hardin, Bullitt, and Meade Counties. This was acquired through the purchase of farms.

The land in the Salt River Basin is now about 84 per cent in farms and has 24 per cent of this total area wooded, some of which is in farm wood lots. Farm crops occupy 25 per cent of the basin and pasture about 44 per cent.

CONDITION OF LAND OTHER THAN FOREST

Corn is the most important agricultural crop and occupies the greatest proportion of the cultivated land. Hay and wheat are of secondary importance. Tobacco is raised, but the acreage devoted to this crop is comparatively small. Truck gardening is important in Shelby, Jefferson, and Bullitt Counties, and orchard fruits are raised on the upland farms. Through the efforts of the State Agricultural College, interest is being aroused in better methods of cultivation to prevent erosion. The steeper slopes have a tendency to wash in closely grazed pastures.

A study of abandoned fields made in Hardin and Bullitt Counties showed 30 per cent reproducing satisfactorily to good species of forest trees, 45 per cent coming back to undesirable species, and 25 per cent washed and practically barren. This record represents fields which have been abandoned for the past 10 to 15 years. Any planting plan adopted for the region must give first consideration to the washed and barren areas.

CONDITION OF FOREST

With the exception of a few small stands the woodland has been severely and repeatedly culled. Inferior species now make up the majority of stands, black oaks predominating on the uplands and

beech on the slopes and in the hollows. On the knobs and ridges in the southwest section of the drainage, some Virginia pine is found in mixture with red cedar, but it does not occur to such an extent as to warrant recognition as a separate type. Practically all of the pine above 10 inches in diameter has been cut.

Fire has burned over practically all forest land in the watershed. In most cases the humus as well as the smaller reproduction has been destroyed, resulting in erosion on the steeper slopes until a cover is reestablished. It is seldom that more than a few years pass without repeated burning of the woodlands. In addition to the destruction of the reproduction the older trees are often damaged to such an extent that it is only a matter of a few years before they succumb to disease and insect attacks. Grazing in fenced wood lots tends to destroy all young reproduction except pine and red cedar. Except in fenced areas, grazing is not severe and the damage is not great enough to attract attention.

PROTECTIVE VALUE OF THE WATERSHED

SOIL

Area	Protective rating
Square miles	
2,654	70
332	50

Weighted average for basin, 68.

TOPOGRAPHY

Rating determined by consideration of the influence of physiographic features upon erosion and stream flow.

Area	Protective rating
Square miles	
254	100
1,806	75
926	50

Weighted average for basin, 69.

PRECIPITATION

The rating determined by consideration of the amount and character of precipitation is 79.

COVER

Area	Protective rating
Square miles	
956	50
717	90
1,313	65
2,986	-----------

Average rating for drainage, 66.

Only about 24 per cent of this watershed is in forest. The pasture on steep land is not able to maintain a good sod except in the bluegrass section. The agricultural land erodes even on rolling land. Thin soiled hill lands in the Knobs and Eden shale belt are subject to erosion when the forest is cut.

Average rating of the basin	Protective rating
Soil	68
Topography	69
Precipitation	79
Cover	66
Average	70.5

CRITICAL AREAS

The average rating of 70.5 for the basin, taking into consideration the condition of soil, the topography, and the climate and cover, does not give the correct impression of this watershed. It contains areas of good agricultural land in addition to the bluff lands along the streams and the rough land on shale, sandstone, and cherty limestone formations. The latter types of land should be retained in forest and the forested areas are in need of improvement.

RECOMMENDATIONS FOR THE WATERSHED

The rough lands of this watershed are scattered over the basin in a way that will make the consolidation of large forest tracts difficult except in the Knobs belt and in the vicinity of Shepardsville. Many other smaller areas of forested hills are found among the steeper cultivated lands of the Eden shale belt. These agricultural areas will eventually erode to such an extent as to force the owners to convert them to grass pasture or abandon them to brush and forest growth. Small demonstration forests owned by the State or county might be organized. The bulk of this forest land will continue in private ownership but organization of effective fire protection is essential for improvement of forest conditions. Planting on abandoned farm lands is desirable.

SCIOTO DRAINAGE AREA

(Area 16)

LOCATION AND AREA

The Scioto River, which drains an area of about 6,361 square miles in the central and southern parts of the State of Ohio, has a generally southerly course and flows into the Ohio River at Portsmouth, at an elevation of 527 feet above sea level. This basin, which is about 150 miles long and 35 to 66 miles wide, lies between the Miami Valley and the Muskingum and Hocking Valleys.

TOPOGRAPHY

The drainage basin of the Scioto contains about 15 per cent hilly land, 25 per cent rolling land, and 60 per cent undulated land or plains. The upper end of the drainage basin is level or rolling,

largely agricultural land with several large towns and cities situated along the banks of the river.

The valleys of the Scioto and tributaries as far south as Chillicothe are shallow with narrow flood plains. A short distance below Chillicothe the hills close in on both sides, and the remainder of the course of the Scioto is through a deep valley bordered by hills 400 feet or more in height.

The Scioto drainage is longer than either the Muskingum or the Miami, so that the gradient of the stream is more gentle. The upper two-thirds of this basin was glaciated and has a deep deposit of glacial drift. Although the drainage has been so well reestablished since the recession of the glacier that there are no natural lakes, there are areas which were poorly drained while the basin was still in forest. These are now largely cleared and cultivated. From the point in Marion County where the river turns south to Columbus, the fall is about 5 feet to the mile. From Columbus to the Ohio, a distance of about 110 miles, the fall is about 2 feet to the mile.

The Scioto Basin north of Chillicothe was shaped by a lobe of the glacier which pushed southward between two high points of land, one in Logan County and the other in southern Richland County. The moraines in this basin are, therefore, found chiefly along the eastern and western edges of the drainage area and in crescent-shaped bands across the valley.

There are two artificial water-storage reservoirs on the Scioto just above Columbus which supply the city with its water.

GEOLOGY AND SOILS

The western side of the upper half of this basin is underlain with Niagara limestone of the Silurian period. Eastward the younger systems appear in order. These are the Corniferous limestones of the Devonian period, the Huron shales, and on the eastern side of the basin, sandstone, limestones, and shale of the Upper Carboniferous, Waverly formation.

Although the rock underlying the greater part of the Scioto drainage is limestone, the glacial drift has a pronounced effect upon the soils. Outcropping bedrock is rare but the glacial drift is partly of limestone origin and therefore calcareous. Silt loams and clay loams are the predominant soil types. Two general classes of soils are recognized: Those which have weathered under well-drained conditions (Miami, Bellefontaine soil series), and those which have weathered under swampy conditions with wash from higher regions (Clyde, Brookston series). For the glacial soils, complete weathering has not proceeded deeper than 20 to 30 inches into the drift, but the drift itself may be very deep. The underlying horizons contain large quantities of rock fragments that provide adequate underdrainage where the topography is rolling. In general, however, the level and undulating topography commonly found in the northern portion of this basin does not favor good drainage for agricultural purposes. Throughout the glaciated region, glacial lake beds and their shore lines are commonly present. The lake beds present an exceedingly level topography, poorly drained, the soils being much heavier than those found in the surrounding regions. The residual

soils of the southern area are silt loams from sandstone and shale, relatively shallow and subject to severe erosion on the steep slopes. The greater part of the region has not been extensively cultivated.

CLIMATE

Weather records have been kept in this watershed for periods of 5 to 92 years. These show that the mean annual precipitation varies from 35.34 to 40.62 inches, with the lowest and highest figures (minimum and maximum) for the extreme years in the period at 23.40 and 57.59, respectively. From about 52 to 56 per cent of the precipitation occurs during the six warm months.

The influence of altitude, latitude, and position relative to the storm track is seen in the snowfall, which is heavier in the headwaters than in the central part of the watershed. Mean annual temperatures range from 49.7° to 55.4° F.

HISTORICAL DEVELOPMENT

The early history of the Scioto Valley is one of land clearing and the intensive development of agriculture. In 1800 this area had a forest cover of 97 per cent—a complete cover with the exception of small openings here and there which were cropped for corn by the Indians. Increased settlement decreased the forested area, so that by 1850 about 50 per cent of the land remained forested; and by 1900 about 25 per cent remained forested. From 1853 to 1883, 1,916,781 acres of the Scioto Valley were cleared for agriculture, or a difference of 44.46 per cent, which gives an annual decrease of woodland within the 30-year period of 1.48 per cent.

Manufacturing industry increased with settlement. While this development has continued, many of the small water-power mills developed up to 1880 have now been abandoned. Outside the manufacturing centered in the larger cities and towns, the population is mainly supported by agriculture.

The land is mostly in farms containing up to 160 acres, with a few large farms and timber tracts.

The land use of the Scioto Valley is as follows (data from United States Census of Agriculture, 1925):

	Per cent
Farm land, cropped	45.0
Farm land, pastured	30.0
Farm, woodland	11.2
Unclassified	13.8

The heading unclassified includes wild land as well as areas in cities or villages, roads, and railroad rights of way.

The total forested land in this basin, including woodland on farms and wild land, is estimated at 14.8 per cent.

CONDITION OF LANDS OTHER THAN FOREST

The cultivated crops are the cereals, such as corn, wheat, oats, and barley, with some orchards. Considerable areas around the larger cities are devoted to truck gardening or are idle pending development.

The pastures are generally productive, with a heavy sod of mixed grasses, principally bluegrass, red top, timothy, clover, etc. Erosion in pasture fields is limited to the steep fields and banks of water courses.

Abandoned fields in the lower part of the Scioto restock quickly to weeds and briars, subsequently coming into forest tree reproduction.

CONDITION OF FOREST

The woodland of the northern part of the Scioto Basin is in isolated tracts surrounded by agricultural land. In the southern, more hilly part of the basin, the forest occurs in larger tracts on the ridge lands, separated by farm lands along the principal roads and the stream courses.

The forest of the northern part of the drainage now contains beech, with sugar maple, ash, and several species of oak and hickory, while some pin oak, elm, and red maple occur on the poorly drained flat land. Cottonwood, silver maple, willow, and sycamore occur along the stream bottoms. Most of the forest may be characterized as upland hardwood. Practically all of the woodlots are pastured and all but a few outstanding examples have been culled severely, only the poorer members of the stand being left.

Beech, which has never had a good sale value, usually has been left when the better old timber was cut. This is now generally overmature and a hindrance to reproduction of the better species.

The farm woods are characteristically open underneath, the result of grazing, and a great deal of the leaf litter is blown out of the smaller wood lots. The lack of a shelter belt of undergrowth around the outer edge of the woods also increases the rate of disintegration of the litter, causing the forest floor to dry out, a condition very detrimental to the older forest trees, especially beech.

The combined influence of cutting of the best trees and pasturage of wood lots has created a defective, open stand, with little second growth. In the last stages of disintegration of these remnants of the old forest growth the woods become a park-like, open stand of trees scattered through a pasture field. Such woodland, without an appreciable amount of leaf litter on the floor of the forest, has little more water-holding capacity than open pasture land. In wood lots where stock has not been pastured, good second growth with a well established humus is the rule.

The forests of the lower half of the Scioto Basin (from Chillicothe south) are composed of white, black, scarlet, and chestnut oaks, maple, beech, yellow poplar, basswood, and chestnut, with small quantities of Virginia, pitch, and shortleaf pines at the extreme southern end of the basin on the dry slopes. Practically all of these stands are second growth, in which considerable cutting has been done, first for saw timber, and later for ties, posts, and poles. The trees that are left are generally inferior in form or species and defective because of fire. In many of the stands, a fair amount of reproduction of good species is present and in thrifty condition, so that with a little care and attention the quality of timber produced could be materially improved.

While no effort has been made to dispose of slash, the fire damage, as a whole, has been better controlled than in the more extensive

forest regions of the Cumberland and Allegheny Plateaus. Where fires have occurred some of the surface soil has washed away, the reestablishment of humus has been slow, and diseased stands of timber or more open character have resulted.

Grazing has done less damage to the forest of the lower Scioto Valley than to the wood lots in the upper part of the valley. This is primarily due to less severe grazing. The area of woodland is larger and stock is not confined so closely as in the small fenced wood lots.

While the northern two-thirds of the watershed and the valleys of the southern part are primarily agricultural land, there are two distinct types of land which should be retained in forest cover. These are the hilly, nonagricultural lands of the southern part of the basin, and those parts of the farms which are unsuited to agriculture or pasturage in the northern part. The bluff lands along streams, or rolling land that is subject to gullying, should also have a timber cover.

Some land in the farms is needed to produce timber for the farm. This includes fuel, posts, and rough lumber. Such wood lots can be used to occupy land not well suited to cultivation.

The Scioto River and its larger tributaries have extensive alluvial bottom lands of fine gravel and silt. During severe floods, these are cut by the streams, and great quantities of silt are carried to the stream channels below.

Further protection from undercutting of the stream banks could be obtained by planting trees along them. The present fringe of willow, poplar, silver maple, and sycamore occupies only such land as can not be cultivated.

PROTECTIVE VALUE OF THE WATERSHED

The following tabulations summarize the protective value of the watershed:

SOIL

Area	Protective rating
Square miles	
5,034	90
376	80
801	70
150	50
6,361	------------

Weighted average for the basin, 86.

TOPOGRAPHY

Area	Protective rating
Square miles	
1,035	75
1,571	85
3,755	100
6,361	------------

Weighted average for the basin, 92.

PRECIPITATION

The protective value of the watershed with regard to amount and distribution of the precipitation has been rated at 92.

COVER

Area	Protective rating
Square miles	
655	50
2, 857	60
1, 908	85
941	90
6, 361	-----------

Weighted average for the basin, 71.

Average rating of the basin

	Protective rating
Soil	86
Topography	92
Precipitation	92
Cover	71
Average	85

The Scioto River has large areas of flat and rolling land in its headwaters and especially on the tributaries west of Columbus. The stream courses themselves are shallow, and water spreads quickly to the adjoining bottom lands. These conditions, combined with the gradual fall of the stream course itself and lighter precipitation, make this basin a better storage reservoir for flood water than the Miami before its improvement. However, the flood plain of the stream from Columbus to Portsmouth is frequently inundated to such an extent as to sever highway communication.

CRITICAL AREAS

Run-off and erosion are most serious in the hill region in the lower third of the valley. This area was not glaciated and its soils are comparatively thin and of clayey character. The topography is very steep. The State has already begun to acquire land for forest in several places in this region in recognition of the need for forest cover.

RECOMMENDATIONS

Extension of public ownership of forests in the lower Scioto Valley.

Protection of banks of streams by willow, cottonwood, and other trees suitable for bank planting.

Protection of the lower valley from fire through adequate support of the State's present program.

Control of grazing on wood lots to prevent destruction of existing woodlands and to build up a leaf mulch.

Planting of abandoned lands. These are chiefly untillable hills, bluffs, and gullied fields.

CLINCH DRAINAGE AREA

(Area 17)

LOCATION AND AREA

The Clinch River has a long, narrow watershed extending down the west side of the Appalachian Valley across western Virginia and part way across Tennessee. This river is one of the principal forks of the Tennessee and flows along the front of the Cumberland Plateau joining the Tennessee about 40 miles below Knoxville. It has one main tributary, the Powell River. The valley is about 230 miles long and about 25 miles wide. It has an area of 4,278 square miles, 2,494 of which are in Tennessee and 1,784 in Virginia.

TOPOGRAPHY

The tributary streams in this basin extending from the west side, have cut back into the plateau and developed deep, narrow valleys with sharp knife-edged ridges. The tributaries entering from the south and east have a much more gentle gradient. Their valleys are wider and the slopes less precipitous. The agricultural lands are largely situated in these valleys, while the principal forest area is confined to the Cumberland Plateau and its outlying ridges.

The absolute range in elevation varies from 705 feet at the mouth of the river to about 4,600 feet at White Rock Mountain in Virginia. Relative elevations vary from about 400 to 1,500 feet between stream bottom and ridge top. The general trend of the mountain ranges is northeast to southwest.

The long, narrow character of the drainage basin is due to the fact that the ranges are folded portions of the Cumberland plateau. The Clinch falls at an average rate of 2 feet per mile for the 150 miles from the mouth of Indian Creek to the Tennessee River. The tributaries draining the front of the plateau are swift and rocky, while those from the south and east are but little swifter than the main river.

There are no swamps or other natural retention basins of any size within the drainage. There had not been any large water-power development up to 1927, but the Tennessee Geological Survey reports that applications for permits have been made for the following sites:

Sites:	Estimated horsepower
Kingston	36, 000
Melton	54, 000
Clinton	30, 500
Cove Creek	100, 000
War Ridge	50, 000
Total	270, 500

The topography of the Clinch watershed has been roughly estimated by classes as follows:

	Per cent of area	Square miles
Mountainous	45	1,925
Hilly	40	1,711
Rolling	10	428
Plains	5	214
Total	100	4,278

GEOLOGY AND SOILS

This basin lies mainly within the Great Appalachian Valley. Narrow ridges and valleys have been evolved by the unequal weathering of sharply folded strata. The valleys are underlain chiefly by dolomitic limestone of the Canadian or Ozarkian age, ascribed to the late Cambrian period. The ridges are of more resistant limestone, shale, and sandstone.

Silty and clayey loams are the common soil types within the limestone valleys. They are of medium depth and occur over a rolling limestone topography. They may often be quite cherty. When abandoned or injudiciously cultivated, these soils have suffered badly from erosion. The ridge soils may be either clayey or sandy, depending upon the rock source. They are often stony and are relatively shallow. When exposed on slopes they are subject to rapid erosion.

A small area of the basin in the extreme southwest portion, drained by the Emery River, lies within the Cumberland plateau. Here the underlying formations are chiefly sandstone and shale, which have given rise to rather shallow stony silt loams or fine sandy loams of the De Kalb series. These soil types wash badly when exposed on slopes and ridges. The fine soil on steep slopes is sometimes washed away to the underlying rock formations.

CLIMATE

The Weather Bureau stations located within this area have records covering from 9 to 37 years. These records show a variation in mean annual precipitation from 48.31 to 57.41 inches, and a minimum and maximum precipitation for the period of about 37 and 69 inches. From 49.4 to 52.4 per cent of the rainfall occurs during the warm season. The entire watershed is located in an area of comparatively high precipitation with a concentration in the vicinity of Crossville, Tenn. Snowfall varies from 14 to 18.7 inches. Mean annual temperatures show a variation from 54 to 57° F.

HISTORICAL DEVELOPMENTS

The upper Tennessee Valley, including the Clinch, was first settled just prior to the Revolutionary War, at which time the broad bottom lands along the Clinch and the east and south tributaries were settled. At a later date development extended south to Tennessee. The first settlers found a practically unbroken stretch of forest and their chief problem was to clear sufficient agricultural lands for their needs.

Consequently some of the finest hardwood stands were slashed and burned to get them out of the way. Prior to 1870 there was no lumbering in the basin except to supply local needs. About this date the development of the lumber industry along the Ohio gave impetus to the driving of the more accessible timber of the better species down the Tennessee. A considerable amount of this timber was floated all the way to the Ohio. Somewhat later sawmills were established along the Tennessee. It was not until 1891, however, with the opening of the Clinch Valley branch of the Norfolk & Western Railroad, that extensive logging was started. The lumber industry passed its peak about 1914. The upper reaches of the Clinch in Virginia were cut out chiefly to supply small mills.

The valley of the Clinch, particularly through Lee and Wise Counties, Va., is underlain by very extensive coal measures. Mining development started with the advent of the railroad in 1891 and is the principal industry in Wise County. Development has not been as rapid in the other two Virginia counties, and it is not expected that the peak will be reached for a number of years. With the exception of the large holdings of the mining companies and several large tracts of grazing lands, most of the valley is held by small owners in blocks of 160 acres or less. The principal crops raised on these small farms are corn, hay, potatoes, and orchard fruits, chiefly apples and peaches. The present status of land utilization in the Clinch drainage is shown in the following table, which was derived partially from data secured by the 1925 census of agriculture:

	Per cent
Farm land:	
Crop land	15.0
Woodland pasture	3.3
Other pasture	23.0
Woodland not pastured	15.4
Waste land in farms	1.3
Total	58.0
Other land:	
Wild land	37.2
Cities, towns, rights of way, etc	4.8
Total	42.0
Total forest land	55.9

CONDITION OF LANDS OTHER THAN FOREST

The grazing industry is important throughout the drainage. Cattle and hogs, and to a lesser extent sheep, are the chief products of this industry.

Considerable land unsuited for agriculture has been cleared on the steeper slopes of the ridges separating the tributaries of the Clinch, particularly in the south and east portions. The general practice seems to have been to clear lands on these steeper slopes and till them four or five years, after which they have been so greatly depleted and badly washed as to render them worthless. In some instances these

lands were seeded down for pasture, but usually they were abandoned and other lands cleared.

With the exception of the cleared lands on mountain slopes, the greater portion of the agricultural lands in this drainage are not subject to severe erosion. Some lands within the coal measures erode badly unless carefully handled. The large holdings of the mining companies have had a favorable influence in preventing the clearing of much land unsuited for agriculture.

CONDITION OF FOREST

The forests are mostly of upland hardwood type with a mixture in some places of both yellow and white pines. The forested area is chiefly confined to the Cumberland plateau and the folded ridges lying between the main stream and the east face of the plateau escarpment. The forested areas south and east of the main stream are chiefly farm woodlots.

The upland hardwood type consists of white oak, chestnut oak, chestnut, yellow poplar, red oak, black oak, basswood, hemlock, beech, sugar maple, and red maple, with smaller quantities of other species. The pines are chiefly confined to the south slopes of the sharp, narrow ridges comprising the east face of the Cumberland plateau. Hemlock occurs sparsely, usually in mixture with hardwoods and along the streams.

Early lumbering in this region removed the better species, which stimulated the reproduction of those less desirable. Subsequent logging operations cut to a smaller and smaller diameter limit until the present stand over much of the area is of an inferior quality. There was no effort toward slash disposal, consequently fires were frequent and of considerable intensity. As a result reproduction was seriously retarded and the quantity of leaf litter and humus is far below normal. Some of the burning results from the desire to open the woods for grazing. Considerable browzing by cattle, particularly on yellow poplar reproduction, is one of the more serious results of grazing the woodlot pastures. Where fires and grazing have been controlled the land is quickly occupied by some type of tree or shrub cover, which temporarily checks erosion and preserves the site quality until such time as reproduction is established.

PROTECTIVE VALUE OF THE WATERSHED

SOILS

Square miles	Per cent of area	Protective rating
1,674	39	80
2,604	61	70
4,278	100	----------

Weighted average, 74.

TOPOGRAPHY

	Square miles	Per cent of area	Protective rating
Mountainous	1,925	45	55
Hilly	1,711	40	70
Rolling	428	10	90
Plains	214	5	95
Total	4,278	100	---------

Weighted average, 67.

PRECIPITATION

General average of precipitation, 51 inches; distribution, poor; per cent of area, 100; protective rating, 62.

COVER

	Per cent of area	Protee- ttvc raiing
Crop land	15	60
Pasture	23	75
Forest	53	90
Improvements	9	50
Total	100	---------

Weighted average, 78.

For the purpose of rating cover all woodland pastures have been considered as pasture, as they are usually of such open character that they more nearly approach the condition of pasture lands.

Average rating for entire drainage

	Protective rating
Soils	74
Topography	67
Precipitation	62
Cover	78
Average	70

CRITICAL AREAS

In the Clinch River drainage the main ridge, which lies between the Clinch and Powell Rivers, the slopes of the divide between the Powell and Holston, and all parts of the Clinch River Basin contained within the Cumberland Plateau, must be considered critical. This ridge land is steep and is unsuited to agriculture because of its topography and the thinness of the soil. The west side of the Clinch River drainage, especially along the Emery River, is occupied largely by the steep ridges of the east front of the Cumberland Plateau. On this edge of the plateau the soils are sandy and poor, especially on the crests of the ridges. The wealth of the Clinch River drainage lies largely in its coal, water power, and timber, and agricultural land will always be restricted to the more level areas

along streams. For the benefit of the coal industry and as a protection against silting of reservoirs, as well as against the destruction of bottom-land farms, the higher land in this drainage system must be kept in forest.

RECOMMENDATIONS

The entire Clinch River drainage should have a well-organized system of fire protection. Within the Cumberland Plateau section, on the slopes of Pine Mountain, and on the main divide between the Powell and Clinch, is opportunity for the acquisition of public-owned forest. In addition to this, coal companies and water-power companies should assist for their own interest in the organization of well-managed forests. A great deal of forest land is in the farms and farmers should be encouraged to grow timber to supply the wood-using industries in the vicinity. The north slopes and coves in this area have a comparatively good stock of yellow poplar, and the extending of this species should be encouraged.

FRENCH BROAD DRAINAGE AREA

(Area 18)

LOCATION AND AREA

The French Broad drainage area lies in the mountain section of western North Carolina and in a portion of the Tennessee Valley. It joins the Holston above Knoxville to form the Tennessee. The French Broad has two main tributaries, the Pigeon and Nolichucky, and one smaller tributary, the Little Pigeon. It has a broad basin bounded along its easterly margin by the Blue Ridge in North Carolina, and it occupies 2,797 square miles in North Carolina and 2,255 square miles in Tennessee—a total of 5,052 square miles. The main French Broad heads in the southern corner of this drainage basin near the South Carolina line. It flows north first, then northwesterly to the Tennessee Valley, where it turns southwesterly. The breadth of the drainage basin exceeds its length.

TOPOGRAPHY

The French Broad River with its tributary, the Pigeon, drains the Asheville Basin and adjoining mountain ranges north of the Blue Ridge, east of the Balsams, and north to include the Unakas, Blacks, and a part of the ranges adjoining the Blue Ridge in the vicinity of Grandfather Mountain.

The central portion of the French Broad drainage may be designated as the Asheville Basin. This is a high, very much dissected plateau. Over its entire surface the streams have cut deep channels, leaving steep rounded hills with sharp valleys and very little flat land.

The mountain ranges include the Balsams. New Found, Blacks, Smokies, Pisgah, Craggies, and Unakas. All have sharp ridges and peaks. The streams have narrow sharp valleys with narrow fertile

flood plains. With the exception of the extreme head of the main river, the French Broad flows through a deep narrow valley which becomes a gorge as it passes through the Smoky Mountain range. This same gorge-like structure characterizes also the Nolichucky and Pigeon, both of which break independently through the Smoky-Unaka range. About 25 per cent of the drainage basin of the French Broad lies in the main Tennessee Valley where the land is rolling to hilly. The French Broad and its two main tributaries are all swift-flowing streams very suitable for the development of power sites.

This river, like the Little Tennessee, drains a very high mountain region of western North Carolina which has a number of peaks exceeding a mile in height. The elevation of the river at its mouth is 802 feet.

The eastern part of this watershed contains two rather broad valleys, the Asheville Basin and the basin about the head of the Pigeon River. The high rim of mountains which incloses these basins extends entirely around them but is lowest near the head of the main French Broad River near the South Carolina line. The high mountain ranges adjoining the Blue Ridge, the Balsam Range, the Great Smoky Mountains, and Upper Unakas very effectively inclose these interior plateaus. Reference to this is made in discussing climate.

GEOLOGY AND SOILS

The western portion of this basin lies within the Appalachian Valley. In this greater valley narrow valleys and ridges have resulted from the unequal weathering of sharply folded strata, chiefly limestone, shale, and sandstone. The soil types of the narrow valleys are loams and clay loams from limestone. These types are fairly deep and well drained, but destructive erosion occurs on abandoned land and carelessly cultivated fields. The ridges of shale and sandstone have shallow and often stony soils which may suffer severely from erosion when exposed.

The central portion of this basin falls within the Unaka Mountain region where the rock formations are of shales, slates, quartzite, and conglomerate. These mountains are old residual ranges of very early geologic origin. The soil types most commonly present are clayey loams and clays from slates and shales, and stony and sandy loams from quartzite and sandstone. The clayey soils are fairly deep and of fair drainage, but they are subject to gullying when exposed. The sandy soils are shallow and suffer from washing and sheet erosion, particularly on the ridges and uplands.

The eastern half of the French Broad Basin falls within the older Appalachian Mountain province and includes a part of the oldest crystalline system exposed on the Continent. The rock formations are schists, gneisses, and granites. The soils are chiefly clayey types from mica schists occurring at lower elevations, or else sandy and stony loam types derived from gneiss and granite. The clay types are often deep. They are not porous, however, and consequently the surface run-off is rapid. Gullying is severe and often becomes destructive on exposed areas. Rock outcrop and rough stony land are common.

CLIMATE

Climatological records taken over a period covering from 10 to 36 years show a variation in mean annual precipitation from 39.86 to 65.20 inches, and a minimum and maximum precipitation of approximately 27 and 101 inches. The precipitation during the six warm months varies from 50.3 to 58.4 per cent of the annual total.

This stream heads in an area of high precipitation in the vicinity of Brevard, N. C. It then enters the Asheville Basin, an area of low precipitation for the State. Throughout the rest of its course precipitation does not exceed 50 inches mean for the year. This amount, however, gives it importance in relation to run-off and erosion. Mean annual snowfall varies in depth from 8.1 to 23.8 inches. Mean annual temperatures varying from 50.3° to 58.4° F. have been determined for the basin. Precipitation is high about the headwaters of the Nolichucky River, and the weather station recently established on Mount Mitchell in North Carolina has recorded new low temperatures for North Carolina.

The mountain-inclosed headwaters of the French Broad drainage basin are subject to wide variations in all climatic conditions. Precipitation is particularly variable, since local storms, some of them very violent, occur throughout the mountainous parts of the basin. Such storms have caused severe local flood damage at a number of places, resulting often in loss of life because of their sudden violence. An extreme case of this occurred in July, 1916, on the headwaters of the French Broad and its tributary, the Swannanoa River, when two days of heavy rain culminated in a flood. All railroad transportation was cut off and the saturation of the micaceous clayey soil caused numerous land slides. These occurred along the southeast front of the Blue Ridge, the east front of Craggy Mountains, and the east front of the Pisgah Ridge. A severe flood in August, 1928, which did not reach the proportions of the one of 1916, again largely cut off the city of Asheville by flooding roads and railroads.

Snowfall is heavier and of longer duration on the higher mountains, lower temperature and higher precipitation resulting in the occurrence of spruce and fir forests on these mountain tops.

The northern exposures are much colder and more humid than the southern faces of the steep ridges. As a result, a cover of hemlock and rhododendron occupies the moist, cool, north slopes, and pine takes the dry, south faces of the ridges.

The French Broad Basin is so located that it is partially sheltered from the storms passing both to the north and to the south of the Appalachian Mountains. At the same time the higher mountains on the south side of this basin may get very heavy precipitation. The Asheville station is the center of low precipitation for North Carolina, while the wettest part of eastern North America is adjacent to the head of the French Broad River only 75 miles south.

HISTORY

The first settlement of the French Broad River came by way of Swannanoa Gap from the east side of the Blue Ridge. Later some of the settlers crossed the mountains in other places and came into

the lower end of the valley by way of the valley of the Holston. The significant part of the history of this valley is that the Blue Ridge shut off transportation for a long period from the east and south, except over poor mountain roads. This isolation continued until the advent of the railroad.

From the earliest times, the settler was attracted by the deep, black soil of the high coves, and cleared his fields here and in the flat gaps or more rounded ridges. Many of these fields are to-day high, steep, and inaccessible. The mountain roads soon became water courses which sunk the roads into deep trenches. This condition could not lead to prosperous farming and it persisted only so long as the requirements of the settler was restrained by his remote location. The first general abandonment of mountain farms came about the time of the Civil War, the next one following in 1890. The chief cause in the later instance was the opening of logging by railroads and the increase in industrial development.

The last 10 years have witnessed another change, the building of good roads extending all over the valley of the French Broad. The increase in size of its cities and towns and the increase in tourist business tend to create a profitable business in farm produce from land close to market centers, so that some of the nearer fields which have produced a scrubby tree cover may be cleared again.

The purchase of several hundred thousand acres of land and the organization of national forests, with its educational effect, have awakened interest in the forests. The progress now being made in acquiring a national park in the Smoky Mountains and especially the need for protection of watersheds to safeguard the supply of potable water, all point to the retention of forest cover on the rough land rather than further clearing.

Within the French Broad drainage basin 2,180,871 acres out of the total of 3,233,280 acres is in farms. About 20 per cent of the total area is in crops, 24 per cent in pasture, and 52 per cent in forest cover. About a third of the woodland in the farms is pastured. The percentage of cultivated land is greatest in that part of the drainage basin west of the Smoky Mountains.

CONDITION OF LAND OTHER THAN FOREST

Farm land in crops is largely used for corn and some other grain, fields are not left long in grass sod, the principal means of fertilization being by cover crops of beans, peas, and clover. Soils of most fields quickly lose their humus content, and erosion on the hilly lands has so reduced the fertility that many have been abandoned for crop production. Such fields are usually pastured and many of them are being covered by a scattered growth of pines. The practice of contour cultivation has not been adopted, nor are other effective means used to check erosion. The bottom lands along many of the small tributaries of the river are washed and covered with gravel periodically by sudden freshets. The small hilly fields require a great deal of hand labor, and crop production can be profitable only when high prices are received for the output.

Orchards occupy a small percentage of the watershed and production of beef stock utilizes a large acreage of pasture land.

FIGURE 4.—A stand of hardwood showing damage caused by fire. Disease has followed the original injury. The recovery of forest litter following former burnings is also shown. French Broad River, N. C.

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FIGURE 5.—Erosion, Ducktown area, Tenn.

CONDITION OF FOREST

THE SPRUCE TYPE

The spruce lands at the head of the Pigeon River on the Black Mountains and part of the Balsam Mountains have been largely cut over and most of them burned. Following the fire, these areas grow up to berry bushes, wild red cherry, and yellow birch, and after a period of 6 to 10 years they have a sufficient cover to prevent erosion. Where burning has occurred the second time, the humus is often destroyed, leaving bare rock exposed. Restocking of the spruce type here will require planting, since no seed trees are left to seed the extensive burned areas. A considerable portion of the French Broad watershed is included in the national forests and in the area set aside for purchase of land for the Smoky Mountain National Park.

Practically all of the hardwood lands in this watershed have been cut over and severely burned repeatedly. They are still covered, however, by the remnant of the forest left after cutting and fire. The majority of the mature trees are fire scarred at the base and unsound. The litter on the forest floor is gradually becoming heavier as a result of protection from fire in the last 10 years. Because of the readiness with which the hardwood forest regenerates itself, no further measures will be needed to maintain a forest cover in this watershed, other than fire protection and judicious cutting. The forest, however, is capable of material improvement in density of the stand, and this will be effected only through the cleaning out of poor trees and culls left after the logging and fire damage.

PROTECTIVE VALUE OF THE WATERSHED

Practically all of the land in this watershed would be subject to severe erosion and rapid run-off were it not for its protective forest cover. This is especially exemplified in the watersheds of the north fork of the Swannanoa River and north fork of the Mills River—two tributaries of the French Broad—which are entirely forested and serve to protect the water supply of the cities of Asheville and Hendersonville. The comparatively small storage dams for both of these water systems are not subject to material silting, and the streams flowing from the forest-covered slopes are comparatively clear throughout the year. The French Broad itself carries a great deal of silt from the agricultural lands, roads, and other places where the soil is not protected by some form of cover. Erosion in the Tennessee valley, where the soil is largely of limestone origin, is comparatively severe on the steeper lands. The ridges in this valley are usually forest covered and this is essential to the protection of the soil.

The protective value of the French Broad watershed should be rated as follows:

	Protective rating
Soils	63
Topography	56
Climate	64
Cover	85
Average	67

CRITICAL AREAS

The entire drainage of the French Broad must be considered as a critical area except for the flat and rolling lands in the Tennessee Valley and a very small acreage of similar land in the valley of the Pigeon River and in the Asheville Basin. The critical conditions is offset, however, by the existing forest cover, which should be extended to those steeper fields now giving evidence of erosion.

RECOMMENDATION FOR THE WATERSHED

The rougher mountain land of this watershed is already included in the area set aside for the purchase of lands for the national forests and the Great Smoky Mountain Park. Some additional mountain land is included within the watershed held by the city of Asheville for the protection of its municipal water supply. As rapidly as possible, the mountain lands included within the purchase area should be acquired either by the National Government or by the States of North Carolina and Tennessee where the lands fall outside the areas designated for Federal purchase.

The completion of the Smoky Mountain National Park will protect a very important mountain area. The lower hills, which are now covered with a low-grade forest, and the abandoned fields, which are now growing up to pine, must remain in private ownership as long as their valuation is held at its present level.

Since all this forest land is capable of maintaining some cover through natural regeneration if protected from fire and grazing, the first essential in improving the forest lands of this watershed is adequate protection of all forested lands from fire. The lands acquired or being acquired by the Federal Government will be adequately protected but in addition there are large areas within the drainage in which the counties will have to organize effective protection systems or enlarge existing organizations through increased appropriation.

HIWASSEE DRAINAGE AREA

(Area 19)

LOCATION AND AREA

The Hiwassee drainage area is very similar in shape to the Little Tennessee and lies southwest of it in Georgia, North Carolina, and Tennessee. This stream enters the Tennessee River about 40 miles above Chattanooga and drains a mountainous area about 95 miles long and totaling 2,702 square miles, 847 of which are in Georgia, 616 in North Carolina, and 1,239 in Tennessee. The stream has two main forks, the Ocoee and Nottely.

TOPOGRAPHY

Its headwaters are rugged and steep, with narrow valleys located among the ridges, which form offshoots of the main Blue Ridge. The Nantahala group is especially rugged. Portions of the valley of

the Nottely River in northern Georgia back of the Blue Ridge are rolling and include agricultural land. The central part of the Hiwassee Valley, where the streams cut through the lower Unakas, has an especially steep topography with the streams in deep gorges. The lower 25 per cent of the basin is generally rolling with some low ridges running northeast to southwest through the Appalachian Valley.

GEOLOGY AND SOILS

The long, narrow valleys and parallel ridges lying within the Appalachian Valley province have resulted from the unequal weathering of sharply folded strata. The valleys are underlain chiefly with a magnesium limestone, known as the Knox dolomite, ascribed to the late Cambrian period, and have developed a rolling limestone topography. The soils are clay and silt loam types, often with an abundance of chert fragments. They are of medium depth and possess good drainage. Nevertheless, erosion has been serious on abandoned lands and carelessly cultivated fields. The ridges are often abrupt, the formations being of sandstone and shale. The soils are thin and wash badly when exposed.

East of the Tennessee Valley, the Hiwassee Basin crosses the Unaka Mountains. Here the underlying formations are of sandstone, quartzite, conglomerate, shales, and slates of early Cambrian age. The soils from the shales and slates are clay types. They are often thin and suffer from washing and gullying when exposed.

An outstanding example of erosion, resulting from destruction of vegetation by smelter fumes, is to be found in this basin immediately surrounding the plants of the Tennessee Copper Co. and the Ducktown Sulphur, Copper & Iron Co. (Ltd.). The latter plant is located at Isabella, in southeastern Polk County, Tenn., and the former about 2 miles farther south, close to the Georgia line. The toxic agent in the smoke emitted from the smelters is sulphur dioxide resulting from the process of working the sulphuretted ores of the region for copper. An area of from 10 to 12 square miles in the immediate vicinity of these smelters has become denuded of natural vegetation with the exception of occasional clumps of sage grass and wild smilax. Bordering this barren region is one varying from 1 to 5 miles in width, covered with sage grass, vines, and a few stunted shrubs and small trees, the latter often with dead tops. Beyond this border of almost treeless vegetation the country is not heavily wooded for some distance. The forest growth is not thrifty and trees with dead or dying tops are numerous. Most of the affected area is in Tennessee, but a large part of it is in the adjacent State of Georgia, and a smaller area lies in North Carolina.

Severe erosion has followed the destruction of the vegetation in this region. The soils have originated from the disintegration of partly crystalline metamorphosed sandstones, quartzites, conglomerates, shales, and slates. The sandstones, quartzites, and conglomerates break down to sandy and rocky soils, while the shales and slates weather to dark, clayey soils of agricultural value. Apparently much, if not all, of the soil within this denuded area is of a sandy or rocky consistency, and this has hastened erosion. The accompanying

illustration shows the extent and severity of erosion following destruction of the vegetation by the smelter fumes.

The easternmost portion of the basin lies within the granite, gneiss, and schist formations of the Blue Ridge. Here the mica schists have given rise to clay soil types with rapid run-off and subject to gullying one exposure. The granite and gneiss give rise to lighter soil types that are shallow on the upland slopes and ridges. These soil types are often stony. They are porous, but they are too shallow to stand washing on the higher slopes, and consequently suffer severely when exposed.

CLIMATE

Weather records for this basin, covering a period of 12 to 46 years, show the mean annual precipitation to range from 50.59 to 66.58 inches and establish the minimum and maximum rainfall records at approximately 37 and 101.57 inches. The entire area is subject to excessive rain, 47.4 to 51.4 per cent of which occurs during the warm season. Snowfall is of little importance, the range of the mean annual fall being from 6.5 to 9.8 inches. Records of mean annual temperature show a range of 57.3° to 59.2° F. The fall season (September, October, and November) is the only one which does not show an excessively high rainfall, especially in the headwaters.

In the lower end of the valley there is a noticeable decrease in precipitation. The mountain valleys in this basin are subject to sudden severe storms.

The months of March and April in the spring and October and November in the autumn are the normal forest-fire seasons in this watershed. The new crop of leaf litter begins to fall about the last week in October, and this leaf fall is completed by the 10th of November. The fall fire season begins as soon as the new leaf litter is dry enough to burn. Through the winter season forest-covered slopes are protected from erosion by this heavy cover of hardwood leaves. It packs during the winter and serves to protect the slopes until the beginning of the growth of new vegetation.

HISTORICAL DEVELOPMENT

Settlement of the Hiwassee Basin was delayed by its landlocked condition. The railroad from the Tennessee Valley to Georgia, passing through the Hiwassee Valley, was built only recently. The early settlement of the valley at the headwaters of the Hiwassee took place from the Georgia side through the low gaps of the Blue Ridge. There is at the present time a large area in the headwaters of the Nottely River, one of the main tributaries of the Hiwassee, which is not reached by railroad. This includes a large part of Union and Towns Counties in Georgia. The timber from this region has been removed largely by stream driving, followed later by railroad logging of that adjacent to the Murphy branch of the Southern Railway and the Louisville & Nashville. Until the last seven or eight years the northwest corner of Georgia, in Union and Towns Counties, has not been provided with good roads. This deficiency has been corrected recently.

Surfaced roads now cross this section both north to south and east to west. A considerable area of agricultural land has been developed around Blairsville, Ga., on the Nottely River, and around the towns of Hiwassee, Hayesville, and Murphy. The ridges in all this section are still covered with timber, which has previously been accessible only to portable mills. The gorge of the Hiwassee is very steep where it passes through the lower Unaka Mountains. Agriculture is better developed on the Ocoee branch of the river. Lumbering, the manufacture of tanning extract, and copper mining on the Ocoee constitute the industrial development of this valley.

Of the total area of 2,702 square miles, 62 per cent is in farms. Of the area in farms 19 per cent is in crops, 12 per cent in pasture, 31 per cent in woodland. The total forest area constitutes about 69 per cent of the area of the watershed. Fifteen per cent of the farm woodland is pastured.

CONDITION OF LANDS OTHER THAN FOREST

Because of the isolated condition of the headwaters of the Hiwassee River and the lack of direct railroad transportation east of the branches of the Southern Railway and Louisville & Nashville entering Murphy, N. C., development has been retarded and many farms abandoned. In the section of this drainage surrounding the towns of Young Harris and Blairsville, Ga., the abandoned fields have grown up to young hardwood stands. Yellow poplar is prominent in such stands, with oaks, hickories, black locust, and chestnut. On the headwaters of the Ocoee River, near the junction of the three States, copper mining has been the chief industry. The present tendency is toward the abandonment of farm land rather than the clearing of new areas. The grazing industry is not extensively developed either for dairy or beef stock. The lower end of the Hiwassee Valley, west of the lower Unaka Mountains, is directly tributary to the region surrounding Chattanooga, which furnishes a market for farm products.

CONDITION OF FOREST

The forest in this region was cut over a number of years ago, and the larger timber was driven down the Nottely and Ocoee Rivers as well as the main head of the Hiwassee. Only the pine, poplar, and other lighter timber could be moved in this way. At the present time there are large areas of comparatively mature timber awaiting cutting in the headwaters of these streams, especially adjacent to the Blue Ridge. Burning the woods is still prevalent, and all standing timber is much damaged by fire. Cattle and hogs are ranged at large in the woods. A rather imperfect fire organization exists on some private holdings in this drainage, but fire protection by the State is very poorly organized in the bulk of it, with no State organization in Cherokee and Clay Counties of North Carolina or Union and Towns Counties in Georgia. Part of the forest on the headwaters of this stream is organized under Federal supervision as the Cherokee and Nantahala National Forests.

PROTECTIVE VALUE OF THE WATERSHED

SOILS

Square miles	Protective rating
894	70
1,808	60

Weighted average for the basin, 63.

COVER

Square miles	Protective rating
513	60
324	75
1,729	90
136	50

Weighted average for the basin, 80.

TOPOGRAPHY

Square miles	Protective rating
1,351	50
946	75
405	85

Weighted average for the basin, 64.

PRECIPITATION

The protective value of this watershed on the basis of amount and distribution of rainfall has been rated at 59. The headwaters of the Hiwassee River are subject to extremely heavy rainfall, amounting in some years to over 100 inches in the vicinity of Ellijay, Ga., and Highlands, N. C. The soil in the lower part of the drainage system is more erodible than that in its headwaters.

Average rating of the basin	Protective rating
Soils	63
Topography	64
Precipitation	59
Cover	80
Average	66.5

CRITICAL AREAS

The topography, heavy precipitation, liability to severe storms, and possibility of erosion combine to make all of this watershed a critical area. The watershed may be considered, however, as comparatively well protected by its forest cover, except in the vicinity of Ducktown, Tenn., where smelter damage has removed the timber. Natural regeneration takes place readily on all abandoned fields.

The forest itself is now being subjected to damage by chestnut blight, and because of the high percentage of chestnut this will materially increase the fire hazard. This large amount of dead wood may so increase the severity of fires in dry years as to kill the entire forest. At the extreme head of the drainage system fires have severely injured the forests, notably about Brasstown Bald.

RECOMMENDATIONS

The Hiwassee is suited to agricultural development only in a few sections. Its topography, soil, and heavy rainfall require a protective forest cover. It is also so situated as to be valuable for recreation and power development. Both these demand good protection against soil erosion.

Where rough mountain and hill lands are not put under proper management by private agencies to insure retention of the forest cover, they should be acquired to the greatest extent possible by State and Federal Governments. The abandonment of fields is evidence of the tendency which may be expected to continue in this region. Permanent industries are needed to utilize the forest crop, and encouragement should be given to promote planting of the idle fields.

Fire has injured the forest. It should be outlawed and the public educated in regard to the damage that it does.

HOLSTON DRAINAGE AREA

(Area 20)

LOCATION AND AREA

The Holston River flows through a valley generally parallel to and east of the Clinch River Valley. The Holston joins the French Broad just above Knoxville to form the Tennessee. It has two main forks north of the Tennessee line and one other large tributary, the Watauga River, which drains a portion of western North Carolina. The Holston River drains the east side of the Tennessee Valley and part of Virginia back to the valley of the New River. The Holston Valley is irregular in shape, about 160 miles long, broad at its upper end and narrow in the lower half. It contains an area of 3,826 square miles, of which 2,270 square miles is in Tennessee, 1,357 in Virginia, and 199 in North Carolina.

TOPOGRAPHY

The Watauga River drains a comparatively mountainous country having an elevation of 4,000 to 5,000 feet at its head. This stream is swift and flows through a gorge at its head, but has comparatively broad bottom lands suited to agriculture in the last 6 or 8 miles of its course. The two forks of the Holston rise in the low ridges of the Iron Mountains and ridges fronting the Allegheny Plateau in western Virginia.

The mountains on the south fork are not so rugged as those further south and rise to elevations of less than 3,500 feet, with the exception of White Top Mountain and Mount Rogers, which extend above

5,000 feet. Along the North Fork of the Holston River the ranges extend in a general northeasterly to southwesterly direction paralleling the front of the Cumberland Plateau.

Topography between the main ridges is rolling, generally cleared for pasture or crops. Only the steeper ridges are forested. The lower end of the Holston River flows through a rugged part of the Upper Tennessee Valley, where the topography is hilly but generally developed for farming. The general level of the land at this point is about 1,800 feet.

GEOLOGY AND SOILS

With the exception of the easternmost portion, the Holston Basin lies entirely within the province of the Appalachian Valley. The basin is made up of narrow valleys and parallel ridges resulting from the unequal weathering of sharply folded strata. The narrow valleys are underlain chiefly with Knox dolomite, a magnesium limestone which on weathering has given rise to a rolling topography. The soils are chiefly silt and clay loam types. They are of medium depth and are fairly well drained. When cultivated injudiciously they have washed badly and on abandoned areas devastation has often resulted through deep gullying.

The intervening ridges formed by the sandstone strata are either narrow and sharp crested or mountainous in character, while the cherty, dolomitic ridges are broad, with rounded or level tops.[1]

The eastern portion of the basin is underlain by formations of quartzite, slates, shales, and sandstone. The soils derived from slates and shales are clayey in texture. They are not porous and allow very rapid surface run-off. On slopes they are subject to deep gullying. Soil types derived from quartzite, sandstone, and conglomerate are sandy and stony. They are shallow and suffer badly from washing. On steep slopes the finer soil particles are often washed away to the underlying rock.

A small portion of the basin on the eastern border comes within the province of the older Appalachian Mountains. Here the underlying formations are of granite, gneisses, and schists. The soils from the mica schists are clayey types with rapid surface run-off and subject to gullying when exposed. The soils from granite and gneiss are shallow, sandy, and of excessive drainage, but on the uplands and steep slopes they wash seriously when exposed.

CLIMATE

A period of 8 to 38 years is covered by the records of climatological stations in this watershed. Mean annual precipitation varies from 41 to 55.21 inches with the minimum as low as 30.69 inches and the maximum as high as 72.95 inches. Of the total rainfall for the year, from 51.3 to 57.3 per cent falls in the warm season. The amount of rain for the three summer months exceeds that occurring in any one of the other three seasons. The upper end of the drainage area

[1] Preliminary Study of Forest Conditions in Tennessee, by R. Clifford Hall, forest assistant, Forest Service. Tennessee Geological Survey, in cooperation with the Forest Service, U. S. Department of Agriculture. Extract (A) from Bulletin No. 10, Forest Studies in Tennessee.

Figure 6.—Severe erosion on land which formerly was under forest cover. Holston River drainage, Carter County, Tenn.

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FIGURE 7.—Area near Konnarock, Va. Logged but not burned. Slash constitutes severe fire hazard but protects the slope from erosion

FIGURE 8.—Area near Konnarock, Washington County, Va., cut for mixed pine and hemlock and hardwood stands. Burned following logging. All shrubbery and trees have been killed. Conditions were the same as in the preceding picture before burning

lies in a belt where snowfall reaches a maximum of 45 inches. Mean annual temperatures range from 49.2° to 56.4° F.

The Holston River, because of its position in the Tennessee Valley between the Cumberland Plateau and the Unaka Range on the east, is naturally protected from storms passing south of the Blue Ridge or up the Ohio Valley. At the same time the narrow character of this valley with high ranges on either side renders it liable to sudden and severe storms, especially on its mountain tributaries. Such a storm occurred in the spring of 1925 on the Doe River and again in the early summer of 1927 in the same section. These severe storms are of considerable local importance and cause floods on the smaller tributaries of the Holston River, but are not of a character to cause floods on the main drainage below.

HISTORICAL DEVELOPMENT

The Holston River was settled just previous to the Revolutionary War period. The first settlement was made at its headwaters by pioneers from the Virginia colonies. This settlement advanced as far as Abingdon, Va. The second settlement of the Holston took place from the mountain section of North Carolina, the settlers crossing from the headwaters of the Catawba on the east side of the Blue Ridge to the headwaters of the Watauga, a tributary of the Holston. These settlements along the lower Watauga and Stoney Creek in Tennessee were the frontier up to the end of the Revolutionary period. From these two sources subsequent settlements of the valley of the Holston occurred. Transportation facilities were poor in this valley until after the Civil War. The only outlets were eastward through Virginia, southward through the Tennessee Valley by way of Chattanooga into Georgia, and by river to New Orleans. The earliest industrial development came through the manufacture of iron. This was carried on in local furnaces which utilized hilltop ore, limestone from the country, and charcoal burned from the adjacent timber. The early output of pig iron was shipped by wagons from many of these furnaces. This activity continued until interrupted by the cheaper supply of iron ore from the Lake States and the general utilization of coke in preference to charcoal. Some few mines, notably the magnetite iron mine at Cranberry, N. C., continued for a time on a coal-burning basis.

The first timber removed from this region was driven through the Holston River to the Tennessee by the long Tennessee detour to its market. Some of it was sawed in mills in the Tennessee Valley.

Agricultural production had not exceeded the local demands until the completion of the railroad from Chattanooga through the Tennessee and Holston Valleys into the valley of Virginia. The agricultural land now in cultivation is insufficient long to maintain the population which is gathering in this valley, but further needs will be supplied from outside sources. Several recent instances of industrial development are significant. Within the past two years the American Bernberg Corporation established a rayon factory at Elizabethton, Tenn., in the Holston Valley. This practically doubled the population of the town, and has in turn been followed by a

second corporation, which is likely to treble or quadruple the population.

Elizabethton was able to attract these corporations through an easily available and adequate water supply from various mountain sources. Other large corporations, including the Mead Fiber Co. and the Tennessee-Eastman Corporation, have recently established themselves in this valley and in the adjoining valley of the Clinch River.

Coal has proved an important factor in the development of the Holston Valley, although none is found in the valley itself. The development of the east Kentucky coal fields and those in the mountain regions of West Virginia have caused the building of railroads, especially the C., C. & C., which crosses the Holston Valley and supplies its industrial establishments with coal.

CONDITION OF LANDS OTHER THAN FOREST

The level and rolling lands of the Holston Valley have been in cultivation for a long period. Chief among the crops are corn, wheat, oats, tobacco, and hay. In the upper end of this valley especially a large part of the hilly land is given up to the production of beef cattle, which are ranged in fenced pastures. Wherever limestone outcrops, good clover yields are obtained by seeding such pastures, and steep slopes may be maintained in sod cover. Only where cultivation has been carried on too long on steep hill lands has the soil eroded and become too poor to support a good growth of grass.

CONDITION OF FOREST

The ridges lying between the several branches of the Holston River are generally forest covered, but the bulk of the forest land lies in the northeast end of the valley in the headwaters. The low ranges of mountains extending from the main Unaka Range are all too rough for cultivation and are forest covered. This includes the Holston and Iron Mountain Ranges, both sides of which are drained by branches of the Holston River, and the western slopes of White Top Mountain and Mount Rogers. The bulk of this mountain country is included in the Unaka National Forest. It has been protected from fire for about 10 years and previous to that time burned periodically. The result is that these ridges are covered with a sprout growth of trees which have sprung up following fire. Some of the territory in the vicinity of Konnarock, lying outside the national forest, has been very severely burned during the past two years. Most of this recently burned land will be converted into grazing land by the sowing of grass seed. Some further clearing of forests for grazing purposes is being done, but the tendency to clear mountain forests is ceasing because of the more remunerative employment in mills and factories and on public works near by.

Lumbering and the fires which followed have been particularly destructive in the northern white pine, hemlock, and yellow poplar forests in the upper Holston Valley.

The cutting of wood for charcoal production has resulted in a sprout forest with an increased percentage of chestnut which now renders fire protection more difficult through the death of prac-

tically all of the chestnut from the chestnut blight. Special precautions will be necessary to prevent destructive fires in these stands.

Fire and careless agriculture have developed inferior secondary types. Dogwood, red maple, sassafras, mountain magnolia, gum, and other undesirable species commonly occupy severely burned areas; and abandoned, waste farm lands frequently seed back to persimmon, sassafras, Virginia and short-leaf pines.

PROTECTIVE VALUE OF THE WATERSHED

SOIL

Square miles	Protective rating
2,878	70
948	60

Weighted average for the watershed, 68.

TOPOGRAPHY

Square miles	Protective rating
1,722	50
1,722	75
268	85
114	95

Weighted average for the watershed, 66.

PRECIPITATION

The precipitation rating of the watershed is 66.

COVER

Square miles	Protective rating
804	60
1,071	75
1,645	90
306	50

Weighted average for the watershed, 76.

Average rating of the basin

	Protective rating
Soil	68
Topography	66
Precipitation	66
Cover	76
Average	69

The rating of protective value for this watershed as shown above takes into consideration the valley as a whole, thereby offsetting the mountainous headwaters against the rolling land in the lower half

of the valley. A truer representation might be secured by examining these two sections of the Holston drainage individually.

CRITICAL AREAS

The mountainous land in the headwaters of the Holston should be protected by a forest cover on account of extensive erosion and run-off. There are also several ridges along the western side of the Holston Valley which are too steep and thin soiled to allow cultivation.

The agricultural and pasture lands of the Holston Valley are found along the east side of the main Appalachian Valley from the mouth of the river back to the vicinity of Marion, Va. In the lower part of the valley the lands are primarily agricultural, while in the Virginia portion the greater part of the cleared land is occupied by fenced pastures. Wherever the soil is of limestone or granite origin, not too steep, cropping and pasturage can be practiced successfully.

RECOMMENDATIONS

Most of the mountain areas in the headwaters of the Holston on the east side of its main valley are already incorporated in national forests. Some extension of the Unaka National Forest might be made in North Carolina, especially on the headwaters of the Watauga River and in the vicinity of White Top Mountain and Mount Rogers. There is also opportunity for the acquisition of publicly owned forests of minor extent on the ridges adjoining the valley of the Clinch River. The State forester of Tennessee has indicated that fire protection should be extended to these ridge lands. Organized fire protection is furnished by the States of North Carolina, Tennessee, and Virginia to nearly all of this drainage which is not protected by the Federal forest force. Improvement can be made in the effectiveness of this protection system.

Stands on the headwaters of the Holston River are just now feeling the effects of the chestnut blight. This will increase the fire hazard and the severity of such fires as occur. The forest will require from 10 to 15 years to recover its density subsequent to the death of the chestnut. As complete utilization of this chestnut as is possible should be effected.

STATEMENT

Portion of report by S. G. Hobart, district forester for southwest Virginia, covering the Virginia portion of the Holston:

Critical forest areas

Area	Present effect	Needs
Clinch Mountain	Beneficial	More intensive fire protection. Reestablishment of forests on abandoned fields. Grazing restricted until forest is established on these areas.
Iron Mountain	do	Better cutting practices.
Walker Mountain	do	Improvement of fire protection. Reestablishment of cover on abandoned fields, with grazing restriction on these areas until cover is established.
River Knobs section	Neutral	Establishment of forest on 50 per cent of the present cleared area.

RECOMMENDATIONS FOR THE WATERSHED

(A) *Areas to be kept in forest.*—At least 400,000 acres should be kept in forest. This figure takes into consideration primarily the critical areas. Assuming that the small patches of forest in the agricultural section are to be maintained as at present, 425,000 acres of forest should be maintained in the watershed.

(B) *Measures necessary to keep present forest land productive.* 1. *Protection from fire.*—Protection should be established in Russell and Scott Counties, and more intensive protection should be made possible over the entire watershed.

2. *Protection from other agencies.*—Not vital at this time.

3. *Proper methods of cutting and forest management.*—The forest should be so managed as to avoid complete removal of the cover and, in the case of pine lands, to provide for the release of stands of young growth now held in check by poor quality hardwoods. The example set by the Unaka National Forest should have a beneficial influence.

4. *Need of forest planting.*—There is no great need for forest planting, as the forest, except a very few areas, can be established where required by natural methods.

5. *Grazing management of forests.*—At the present time grazing management is required only where the stand is being reestablished.

LITTLE TENNESSEE DRAINAGE AREA

(Area 21)

LOCATION AND AREA

The Little Tennessee River flows into the Tennessee about 25 miles below Knoxville. Like the Watauga, French Broad, and Pigeon, this stream breaks through the mountains which form the North Carolina-Tennessee boundary. The river rises in western North Carolina close to the Georgia line and flows in a generally westerly direction to the Tennessee. The basin is about 80 miles long by 35 miles wide, almost entirely in mountainous country. It occupies a total area of 2,549 square miles, of which 1,780 square miles are in North Carolina, 726 square miles in Tennessee, and the rest in Georgia.

TOPOGRAPHY

The Little Tennessee River heads back of the Blue Ridge on the west side of the Balsam Mountains and drains the country to the north of the Nantahala Mountains. Much of this country reaches an elevation of 5,000 feet. The peaks and ridges are sharp, the slopes of the mountains steep, and the valleys narrow, in many cases becoming deep gorges. The Little Tennessee breaks through the Smoky Mountains in a deep, narrow gorge. The general character of this entire drainage area is such that the construction of roads and railroads is extremely difficult, but the character of the stream gorge offers favorable sites for power dams, some of which are now being constructed.

GEOLOGY AND SOILS

The extreme lower end of this basin lies within the Appalachian Valley and is underlain with a limestone, shale, and sandstone formation common to this province. The topography consists of narrow valleys and parallel ridges extending northeast to southwest, which have developed from the weathering of sharply folded strata. The valleys are underlain with a magnesium limestone (Knox dolomite). This has given rise to silt loams of medium depth and relatively good drainage because of the rolling topography. They may sometimes contain abundant chert particles. Under conditions of careless cultivation or exposure of abandoned land, severe washing and gullying have frequently occurred. The ridges are made up of sandstone and shale and are often steep sided. The ridge soils are thin loams that suffer severely from erosion when exposed.

East of the Tennessee Valley this basin includes a part of the Unaka Mountain Range. Here the rock formations are slate, shale, quartzite, and conglomerate. The soils are clayey types from slates, or sandy types from sandstone quartzite. The clayey soils are of medium depth and allow a rapid surface run-off. Gullying is prevalent on cultivated slopes. The sandy soils are shallow and though of good drainage are subject to severe washing when exposed on steep upland slopes.

The easternmost portion of this basin lies within the region of cross ranges extending north from the Blue Ridge. The underlying formations are granite, gneisses, and schists. On weathering, the mica schists have given rise to deep clayey soils. Surface run-off is rapid, and the soils are subject to gullying when exposed on slopes. The granite and gneisses give rise to shallow sandy soils which are often stony and subject to severe washing on the ridges and steep slopes. The outwash from steep topography often brings down gravel and rock fragments which are spread out over the flat lands.

CLIMATE

This entire watershed is located in an area where the high rate of precipitation makes it important with respect to run-off and erosion. The range in mean annual precipitation as shown from records covering a period of 11 to 35 years, is 47.12 to 82.75 inches, with amounts recorded for the lowest and highest years during the period at about 38 and 111 inches, respectively. From 43.9 to 51.7 per cent of it falls during the six warm months (April to September). This rainfall is well distributed through winter, spring, and summer, with the fall season driest. The summer precipitation (June, July, and August) is somewhat higher than that in the winter or spring. The area around Highlands, N. C., is in a region of particularly high precipitation. Mean annual temperatures vary from 50.5° to 55.9° Fahrenheit.

HISTORICAL DEVELOPMENT

Settlement of the Little Tennessee River occurred first at its mouth, and later in the extreme head, which was approached from the valley of the Pigeon. The middle of the Tennessee Valley is extremely rugged, and agricultural development has never been ex-

tensive there. Logging operations were delayed on this stream because of the difficulty of driving it, and virgin timber on a large part of it has been removed only recently, since the development of the Murphy branch of the Southern Railroad. The gorge of the Little Tennessee, at the point where it passes through the Smoky Mountains, is so rugged as to prevent the building of a railroad up this tributary.

Of the total area in the Little Tennessee drainage, 12 per cent is in farm crops; 13 per cent is in pasture on the farms; 21 per cent of the farm area is woodland. Of the total woodland on the farms only 25 per cent is pastured.

CONDITION OF LANDS OTHER THAN FOREST

The farm land in the Little Tennessee drainage is rapidly reverting to a wild condition. The steep fields in the vicinity of Franklin, N. C., and along the Murphy branch of the Southern Railroad are well cultivated in small patches for a few years and are then abandoned. Very little new land is being cleared, but in the last few years some old fields have been recleared of underbrush. Instances of very severe gully erosion can be found on this steep land. Most of the forage is utilized by beef stock; there is a very small percentage of dairy cattle.

The recent increase in public works, notably the construction of highways and storage reservoirs, has given work to the rather scattered farm population. Property values in this territory have been severely affected in the last several years by unjustifiable inflation, the aftermath of the Florida land boom, based on recreation values.

CONDITION OF FOREST

The forest of this watershed has been nearly all cut over except for relatively small virgin blocks along the backbone of the Smoky Mountains and some small blocks of timber in the Nantahala Mountains. The valley is now the site of several active lumber operations. Logging is extremely difficult and the cull grades have regularly been left in the woods when the best of the timber has been removed. Fires have been prevalent and even now the protective system is unorganized in several counties in this drainage in North Carolina. Depleted forest land will be restocked with trees if adequate protection from fire and grazing is supplied. The damage done in past years by these two agencies will be evident in the culled condition of the forest for many years, but effective protection for two decades will greatly increase the density of the forest.

PROTECTIVE VALUE OF THE WATERSHED

SOIL

Square miles	Protective rating
395	70
2,154	60

Weighted average for the basin, 62.

TOPOGRAPHY

Square miles	Protective rating
2, 167	50
306	75
76	85

Weighted average for the basin, 54.

PRECIPITATION

The rating is 58.

COVER

Square miles	Protective rating
306	60
331	75
1, 734	90
178	50

Weighted average for the basin, 82.

Average rating for the basin	Protective rating
Soil	62
Topography	54
Precipitation	58
Cover	82
Average	64

CRITICAL AREAS

With the exception of the small percentage of land in the mouth of this valley and the flatter agricultural lands around Franklin, N. C., and narrow belts along some of the stream bottoms, all of the basin should be retained in forest cover. Adequate protection from fire is all that is necessary. No other tributary of the Ohio River has as high a percentage of rough land or a higher precipitation in its headwaters.

RECOMMENDATIONS

The area is now occupied by large blocks of national forest, including portions of the Nantahala, Pisgah, and Cherokee. Some land which might well be acquired by the Federal Government is still held by private companies. A considerable block of an area designated for purchase for national-park purposes lies in this drainage. After the Federal Government has completed its national park program for this region there will probably still remain considerable areas of forest land on outlying low ridges which must be retained in forest cover and protected from fire for the benefit of this drainage. Increase in the percentage of forest land is made more desirable by the recent increase in storage reservoirs on this drainage. Improvement in the State fire protective organization is required for the adequate protection of this territory. Organization through

FIGURE 9.—On steep hillsides in the mountains exposure of the soil by removal of the forest often results in the soil being stripped from bare rock. Valley of Scotts Creek, Jackson County, Tenn.

380—1

FIGURE 10.—Erosion on white and yellow clay soil, Lawrence County, Tenn.

380—2

the counties has not proved effective, since several counties have abandoned their fire-protection organizations after several years' trial.

TENNESSEE DRAINAGE AREA (DIRECT)

(Area 22)

LOCATION AND AREA

The main tributaries of the Tennessee have been discussed separately. The remainder of the Tennessee Basin is drained directly by the Tennessee River through a number of short streams and three medium-sized tributaries—the Duck, Elk, and Sequatchie Rivers. The basin is generally crescent shaped and includes an area of 22,016 square miles, of which 13,283 square miles is in Tennessee, 6,739 square miles in Alabama, and the rest in Georgia, Kentucky, and Mississippi.

TOPOGRAPHY

The Tennessee drainage (direct) as discussed here excludes the five main tributaries—the Clinch, Holston, French Broad, Little Tennessee, and Hiwassee. The lower Tennessee Valley, the southern end of the Cumberland Plateau, parts of the Highland Rim, the central basin of Tennessee, and the hill region of west Tennessee all drain directly into this part of the river. In the lower Tennessee Valley the land is rolling with low ridges paralleling the valley. The river then passes through a narrow gorge between the Walden Plateau and Lookout Mountain into a narrow valley which is an extension of the Sequatchie Valley. In northern Alabama the Tennessee cuts through the lower end of the Cumberland Plateau and turns north on the west side of the hilly Highland Rim section of Tennessee.

The area drained by the Tennessee direct is about 25 per cent mountainous, 45 per cent hilly, 23 per cent rolling, and 7 per cent undulating to level. The river falls from an elevation of 803 feet at the junction of the French Broad and Holston to about 280 feet at the mouth. The rate of fall is about 1.3 feet to the mile for the first hundred miles, and with the exception of several shoals is less than a foot to the mile for the rest of its course. One tributary, the Elk River, falls about 130 feet over a series of shoals in a distance of 90 miles. The Duck River falls from 450 feet of elevation to about 326 feet at the Tennessee, in a distance of 70 miles.

GEOLOGY AND SOILS

The lower portion of this basin drains a small area of the Purchase [1] region of Kentucky. Interbedded sand and clays of recent geologic deposition (Eocene) underlie this area. Recent alluvial deposits occur along the river bottoms. The upland soils are silt loams of medium depth. With excessive cultivation, washing, and gullying has been severe even on the moderate slopes.

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[1] That portion of the State lying west of the Cumberland River was purchased from the Indians in the treaty of 1819, and from that receives its name.

In the State of Tennessee most of the drainage basin west of the Tennessee River is underlain with beds of unconsolidated sands and clays with marl and lignite. These beds were formed during the Cretaceous period. The area is of coastal marine origin and represents an early formation in the southern coastal plain region. The soils are sandy and clay loams. The soil types are of a structure that renders them extremely subject to erosion, presenting one of the serious erosion problems in the Ohio Basin. Within this basin portions of Henry, Benton, Barrol, Henderson, Chester, and McNairy Counties have suffered severely from washing and gullying. These counties contribute a part of the 115,000 acres held by gullies and the 230,000 acres of abandoned cleared land coming under the influence of gullying in western Tennessee.[2]

That portion of the basin beginning east of the river in western Tennessee and extending into the Highland Rim section is underlain with limestone, sandstone, and shale of the Mississippian period. This region, in a general way, forms a belt that encircles the central basin of Tennessee, passing through northern Alabama and making up the area between the central basin on the east and the Cumberland Plateau. Residual silt loams are the principal soil types found, but the soils vary throughout this belt. The soils from the upper Mississippian formations are from the purer limestone and are less sandy. They form a more even topography when weathered. The soils from the lower Mississippian formations are from sandstone and cherty limestone. They are more sandy and often stony. Throughout this belt excessive erosion occurs under careless cultivation.

The geological history of the surface of the Tennessee River Basin is in part associated with the uplifting and unroofing of the Nashville Dome. In this process the upper formations were removed down to the Ordovician limestone that now underlies the Central Basin. The younger Devonian formations are consequently exposed in a narrow belt that forms with the lower Mississippian limestone the escarpment of the Highland Rim plains.

Residual silt loams from limestone are the prevailing soils of the Central Basin. They are fairly well drained because of the topography. As a rule, erosion has not been serious, but leaching and washing of these soils has rendered some of the fields too poor for cultivation.

Silty and sandy loams with considerable cherty material, are common soil types of the Highland Rim. These have been derived from poor limestone, sandy shales, and sandstone. They are fairly shallow or of medium depth, often stony in character, and frequently subject to destructive erosion when exposed.

The Appalachian Plateau province crosses this basin as a broad belt in the west central portion. The sandstone and shale formations that underlie the plateau region have given rise to silt and fine sandy loams. These are relatively shallow on the upland slopes and have been destructively washed when exposed. On flat, sandstone-capped surfaces, the soil is very sandy and shallow.

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[2] Estimated by State Forester, R. S. Maddox.

The eastern portion of the basin includes a part of the Tennessee Valley. Here the topographic features of long, narrow valleys and parallel ridges have resulted from the unequal weathering of sharply folded strata. The valleys are underlain chiefly with a magnesium limestone. Their soils are loams of medium depth, which wash badly when carelessly cultivated and abandoned. The ridges are made up principally of sandstone and shale, which give rise to rather shallow stony soils that are severely washed when exposed.

A very small area within the Unaka Mountains is drained by the Tennessee Basin. The soils here are either clay types from slates and shales that wash severely when exposed, or else shallower sandy types from quartzite and conglomerate. The latter soils suffer considerably from erosion when exposed on slopes.

CLIMATE

Mean annual precipitation in this watershed, as shown by climatological records covering a period of 12 to 55 years, ranges from 44.01 to 55.99 inches, with the minimum and maximum at 29.08 and 81.02 inches. The region in north Alabama is particularly subject to heavy rainfall. The highest annual fall for the period, 80 inches, occurred at Huntsville. The rainfall over the whole drainage is heavy, and is noticeably higher during the winter and spring seasons. Snowfall is of little importance, the range being from about 3 to 11 inches. Temperatures from 57.8° to 61.1° F. have been found in the mean annual temperature record.

HISTORICAL DEVELOPMENT

The valley of the Tennessee from Knoxville to Chattanooga early became the chief highway of the eastern portion of the State, and the low pass south of Chattanooga made it the gateway to the Piedmont and coastal plain regions to the south. Below this city the Tennessee Valley in making its wide detour around the Cumberland Plateau cut a deep gorge and is too indirect to make it a route through which settlement or commerce could pass to advantage.

The history of the Tennessee Valley is one of land clearing for farming on the better limestone areas and lumbering of all timber as it became accessible. Also some mining has been carried on. Coal mining is less important in the southern Cumberland region than farther north.

Recent power development has brought the valley into a new epoch, which promises greater industrial activity. Power dams need the best possible protection of slopes against silting.

Land utilization in this valley is indicated by the following percentages from 1925 Census of Agriculture:

	Per cent
Crop land	27
Pasture	14
Forest (estimated)	50
Other	9

CONDITION OF LANDS OTHER THAN FOREST

A great deal of farm land has been cleared in this valley which should have been retained in forest. Erosion and subsequent abandoning of fields is especially prevalent in the plateau section of west Tennessee where the soils are particularly subject to erosion. The steeper limestone lands of the Highland Rim and ridges in the main Tennessee Valley above Chattanooga have also been washed following clearing and cultivation. The portion of the Cumberland Plateau tributary to this stream contains a great deal of poor, sandy land. Some of this has been cleared and cultivation attempted, but subsequently the land had to be abandoned. The amount of land of this class can not be stated for lack of satisfactory data. Maddox has discussed this condition in a report covering the entire State of Tennessee. (See Appendix.)

CONDITION OF FOREST

The forest on the southern Cumberland Plateau is composed of several species of oak with short leaf and Virginia pines. The site on the top of this plateau is poor because of the sandy character of the soil. The forest has been seriously abused by cutting and fire. The present stand is composed largely of cull trees left from logging operations which have put on added growth. A large part of it, where still merchantable, contains only ties and low-grade saw timber.

Outside of the Cumberland Plateau the woodlands of the Tennessee Valley are largely in wood lots. These have been subjected to the usual practice of selection of the best species, fire, and pasturage. Though some improvement has been made in protecting such areas from fire during the past 15 years burning is still frequent.

PROTECTIVE VALUE OF THE WATERSHED

SOILS

Square miles	Protective rating
5, 148	80
13, 168	70
94	60
3, 606	50

Weighted average for the valley, 69.

TOPOGRAPHY

Square miles	Protective rating
5, 504	50
9, 907	75
5, 064	85
1, 541	90

Weighted average for the valley, 72.

PRECIPITATION

The protective value of this watershed in terms of the amount and distribution of precipitation has been rated at 66.

COVER

Square miles	Protective rating
5,944	60
3,082	75
11,009	90
1,981	50

Weighted average for the valley, 76.

Averaging rating for the basin

	Protective rating
Soils	69
Topography	72
Precipitation	66
Cover	76
Average	70.7

CRITICAL AREAS

The sandstone lands of the Cumberland Plateau are porous and free from washing on comparatively level surfaces, but they are in need of better cover to increase the litter and humus on the forest floor. The entire Cumberland Plateau section, wherever lands are steep or soils bare and sandy, is suited primarily to the production of timber. It does not make satisfactory pasturage. Forest cover should also be maintained on ridges in the valley above Chattanooga, the hill lands of the Highland Rim section, and the very erodible area of the west Tennessee Plateau.

RECOMMENDATIONS

Extensive areas of publicly-owned forest should be acquired in the Cumberland Plateau region, with a smaller area which might well be State-owned in the southwestern portion of the Highland Rim region east of the Tennessee River. Other critical areas are less suited in size of contiguous forest tracts for the development of large publicly owned forests. County or municipal forests might be established in such sections as the plateau lands in west Tennessee and on ridge lands in the upper Tennessee Valley. In northern Alabama, an area of national forest already exists to serve as a demonstration area south of the Tennessee River.

Well-organized protection from fire under State supervision should cover all the woodlands of this section. Improved methods of forest management should be introduced. Such areas of timberland as that owned by the University of the South at Sewanee, Tenn., as well as State and federally owned forests should be put in good condition to serve as demonstrations. A liberal policy of distribution of planting stock should be followed by the State to encourage farm owners in improving their woodlands.

WABASH DRAINAGE AREA

(Area 23)

LOCATION

The Wabash River is the most important tributary of the Ohio except the Tennessee. It drains an area of 32,912 square miles, of which 24,080 square miles is in Indiana, 8,600 square miles in Illinois, and 232 square square miles in Ohio. The river has its source in Ohio not far from the Indiana-Ohio State line. After entering Indiana, its course is southwesterly until near the Illinois line, where it turns south. From a short distance below Terre Haute to its junction with the Ohio River the river serves as a State boundary. The Wabash with its tributaries, exclusive of the White and Patoka Rivers, constitutes about one-third of the drainage area of Indiana,[1] and including these rivers it drains 66.8 per cent of the land surface of the State. This river also drains an area in southeastern Illinois. It has one main tributary, the White River, which enters from the east and has two main forks. Other major tributaries are the Patoka and Tippecanoe Rivers in Indiana and the Embarrass and Little Wabash Rivers, which drain portions of eastern Illinois. During the last glacial period the Wabash drained the lake which occupied the basin of Lake Erie.

TOPOGRAPHY

The Wabash River has within its basin areas of Wisconsin and Illinoian glaciation and also a considerable portion of the unglaciated Knobs region of southern Indiana.

In general, the country within the zone of the Wisconsin glaciation is gently rolling and undulating in nature. In places almost level till plains are found over large areas.

> The areas drained by the Tippecanoe and Eel Rivers are largely as they were left by the Wisconsin glacial invasion. Many lakes and marshes prevail and drainage is very imperfect. The headwaters of these streams north of the Wabash Channel are the areas of greatest glacial deposition and are practically unmodified by running water. These streams at no place in their headwater regions come in contact with bedrock.[1] The main Wabash Channel has cut through to underlying formations in many places below Huntington,[1] especially along the valley bluffs.
>
> All drainage south of the Wabash River within the area of Wisconsin drift is much better developed. No lakes exist. The streams are frequently entrenched rather deeply in the glacial drift and are rather swift. Locally bedrock is exposed.
>
> Below Terre Haute the Wabash Channel meanders over a wide flood plain which is high above the old bedrock floor.
>
> Since the two forks of White River and certain of their tributaries were the outlet channels of glacial waters and their charge of rock material, their valleys are aggraded more deeply than any of the streams which were not so affected and their gradients are accordingly steeper.[1]

South of the edge of Wisconsin glaciation lies the Illinoian drift belt. In places it is quite hilly and rugged. The reason for this is

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[1] C. A. Malott, Handbook of Indiana Geology, Department of Conservation, Indianapolis.

that the Illinois drift is of much earlier origin, is more easily eroded, and has allowed the streams to cut deeper into the plain.

The unglaciated area proper includes the Knobs Region of southern Indiana. It is characteristically well drained with steep and sometimes precipitous slopes and valleys of varying width. The East Fork of the White River cuts through this region, and the headwaters of the Patoka River are found within it. The streams of this region are flooded during the wet seasons and dry or very much diminished in dry weather.[2] An exception to this exists in the Mitchell limestone belt in Montgomery and Crawford counties. Here the drainage is subterranean, making flow more uniform.

The range in elevation for the Wabash drainage basin varies from 313 to 1,285 feet above sea level. In the Wisconsin drift area the change is very gradual from 700 to 1,285 feet. In the Illinois drift area the country is rougher and rises more quickly from 500 to 1,000 feet. The unglaciated portion shows by far the most abrupt rise, from the valley floors at 700 feet to the hilltops at 1,000 feet. The drainage opens gently toward the south and southwest.

Drainage in the Wisconsin drift area is markedly poor. This has led to the dredging out of ditches and streams and the straightening of stream channels on an extensive scale. Through the northern section of the basin, some dredging has been done in nearly all important streams. Dredging in the Illinois drift area is not so extensive since the drainage is better established, the stream beds being cut to bed rock in some places.

According to Charles C. Dean, formerly State forester of Indiana, one possibility for an impounding basin exists in the lowlands of Knox County on the Wabash River. Although the soil is fertile, the infrequency of cities and inhabited areas makes it a desirable site.

The streams of this drainage are not important from a power development standpoint. There are a few exceptions, but in general the fall in the stream beds is too gradual, the flow too erratic in many of them, and the flood plain too wide. Floods also tend to change the stream courses easily.

The topography of the Wabash Basin may be divided roughly as follows: Hilly, 25 per cent; rolling, 65 per cent; plain, 10 per cent.

GEOLOGY AND SOILS

The western portion of the Wabash Basin comes within the northern extension of the western coal fields of Kentucky. It therefore contains formations of the same age as those occurring in the Appalachian Plateau region. The underlying formations are sandstone, shale, and coal of the Pennsylvanian. Crossing the basin in a northwest-southeast direction east of the coal formations lie three belts of preceding (older) rock systems. These are the limestone, sandstone, and shale of the upper and lower Mississippian (Carboniferous period) and the shales and limestones of the Devonian period. The remaining eastern portion of the basin is of Silurian Niagara limestone, and a narrow belt of Devonian shale and limestone extends along the northernmost portion.

[2] 39th Annual Report Department of Geology and National Resources, Indiana, 1910.

The underlying rock formations have had only an indirect influence upon the soils throughout most of the Wabash Basin, as most of the area has been glaciated and is covered by a deep layer of glacial drift. The drift varies in different localities, depending upon the character of the rock which has entered into its formation and upon the degree to which the drift material has been reworked by water and wind.

The soils have been derived from the weathering of the upper surface of the drift material. The conditions of drainage and exposure under which this surface has weathered has determined the character of the resulting soil. The soils from glacial lake regions are particularly influenced in this manner. The lake beds may be very flat and poorly drained, the present soil being rich in organic matter and of rather heavy texture.

The portion of south central Indiana known as the Knobs Region has not been glaciated. Here the topography is rough and the soils of poorer quality. The loessal mantle of glacial silt is thin or lacking in this area. Over considerable areas there occur sandy and silt loams which in places are stony. In many places the residual soils, which are derived from limestone formations, present a bright reddish color, indicative of long exposure and an advanced stage of oxidation.

A large area of the Wabash Basin has been artificially drained for agricultural use, and on such level or undulating areas surface erosion is not considered a problem. In the rougher topography of south central Indiana soils have washed seriously in some sections.

In the northwestern portion of the basin considerable sand has entered into the surface layers of the soil. This sand is partly from beaches of lakes that have since disappeared or altered their boundaries. This soil is naturally porous.

CLIMATE

Records from the climatological stations in the Wabash drainage cover a period ranging from 5 to 52 years. They show a range in mean annual precipitation from 33.32 to 52.05 inches and a variation in mean minimum and maximum rainfall from 18.86 to 65.66 inches.

The northern part of the area receives about 10 inches less precipitation than the southern part. The effects of latitude are apparent in the snowfall records, a greater quantity falling in the north. The actual range is from 9.9 to 37.8 inches. Warm season precipitation makes up from 49.2 to 62 per cent of the total for the year. It is also significant that the lower part of the basin is subject to more severe rainfall in the spring (March, April, and May). The excessive rainfall in this section is of particular importance from a run-off standpoint. The more nearly precipitous slopes make agricultural soils and those otherwise exposed more susceptible to erosion. This is most important where the soil is thin and the point of saturation is reached quickly, giving rise to increased liability to landslides, especially where such soil rests on inclined bedrock.

The heavy rainfalls, frequent in Indiana, produce enough run-off so that the soil on even fairly gentle slopes is eroded and carried away, if loosened. Many of the long cultivated steeper slopes of southern Indiana have lost so much of their soil as to have become distinctly infertile.[3]

[3] Loc. cit., p. 15.

Mean minimum and maximum temperatures range between 38.3° and 68.9° F., while the mean annual variation is from 50.6° to 56.1°.

HISTORICAL DEVELOPMENT

Practically all of the Wabash drainage except the prairie areas in the northwest part was originally forested. In its original state, the basin contained innumerable patches and areas of poorly drained land bearing an elm-ash-maple or a bur oak-pin oak forest. In the aggregate this was a very considerable area. Whether in stream bottom or on flat upland, the capacity of this large forested area to retard the rapid run-off of heavy precipitation was a very real and far-reaching influence. Interspersed among the more poorly drained areas were slopes and rolling areas bearing a forest composed of varying amounts of beech, maple, walnut, white and black oak, yellow poplar, and other species. This forest gave ample protection to the sites and soils on which it grew.

With the advance of civilization, many of the pioneers located on the rolling, timbered, and well-drained lands in preference to the flat swampy lands. This resulted in the early clearing of those lands which were most subject to erosion. The development of transportation and drainage drew farmers to the more level sections, and left the hill lands in a partly cleared, deteriorated, and eroding condition.[4] The forest disappeared rapidly after settlement and by 1910 the State of Indiana ranked third in the value and amount of its improved land. Agriculture developed to such an extent that forests were regarded as hindrances. The wood lot ceased to be valued for fuel production because of proximity to the coal fields. Dairying expanded so rapidly that available forest land became pasture. Nearness to such markets as Chicago, Cleveland, Detroit, and Cincinnati has enhanced the value of the land for agriculture to the detriment of the wood lot. The remaining forests are found in small tracts. Large contiguous areas of more than a few hundred acres are the exception. For the most part, woodlands are owned by farmers who operate them as a part of the farm, usually included in the pasture.

The southern 34 per cent of Indiana includes 45 per cent of the forest and 48 per cent of the waste land.[5] Of the total area (32,912 square miles) in the Wabash Basin about 54 per cent is in crops, 13 per cent is in plowable pasture, 4 per cent in nonplowable pasture, and 8.8 per cent in woodland. About 5 per cent is unclassified land on the farms and the remainder is unclassified lands in roads, railroads, cities, and towns.

CONDITION OF LANDS OTHER THAN FOREST

The land of the Wisconsin drift area is almost entirely utilized for crops or pasture. Only a very few wood lots are unpastured. Both soils and topography are suitable for cultivation without severe erosion, with the exception of bluff lands along the streams.

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[4] Loc. cit., pp. 14–15.

[5] Department of Conservation, State of Indiana. Map prepared by the Division of Engineering for the Division of Forestry.

South of the Wisconsin drift area erosion becomes a more important factor and even under the best of treatment the soil is held in place only with difficulty on the steeper improved lands. Here the areas of unimproved and waste land increase noticeably. Such areas, reproducing to sassafras and persimmon, coarse grass and weeds, exhibit the most severe examples of erosion in the Illinois drift area. Similar waste lands in the unglaciated section are even more susceptible and include the most critical areas in the drainage. Sod itself seems to be only a temporary help. Some pasture lands show no washing while others on similar slopes are eroded severely. Sheet erosion is common.

CONDITION OF FOREST

The stands of the Wabash drainage are chiefly of the upland hardwood type. The lowland hardwoods are largely restricted to the swamp areas along the Wabash River. Very little virgin timber remains in either type, most of the stands being second-growth wood lots.

Logging alone is not responsible for the poor condition of much of the forest. Where grazing and fire have not occurred the hardwood timber has reestablished itself well. On much of the logged area sassafras and other poor tree species occupy a good part of the land. This is due primarily to pasturage. On wood lots where grazing has followed cutting of the best forest growth the remaining old trees are scattered and parklike.

Fire is not the most important factor; since large, contiguous areas of forest do not exist. Where fire does occur, it destroys the collected litter and humus, exposing the mineral soil, thereby increasing erosion and reducing the protective value of the woodlot.

Grazing is important over the whole area but is of particular consequence from an erosion standpoint in the hills of southern Indiana. By prohibiting reproduction it ultimately causes the disappearance of the forest, exposing the land to the elements.

Some discussion has arisen as to the effects of drainage in the northern part of the area. The failure of crops has been blamed on dredging operations which lower the water table. "Others maintain that the removal of the forests in the eastern part of the United States has been the cause of the apparent lowering of the ground water level from 10 to 40 feet."[6]

Bluff lands along the rivers in this drainage area are still partly forested though usually pastured. The flat lands back from the bluffs are in pasture or cultivated. Deep ravines along some of these bluffs are continuing to erode and cut into the cultivated land above. These will in many cases require mechanical checks. Once erosion has been checked these ravines should be forested.

PROTECTIVE VALUE OF THE WATERSHED

SOIL

About 57 per cent of the area is in the Wisconsin drift section, 6 per cent is in the driftless area, and 37 per cent in the lower part of

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[6] McGee: 35th Annual Report, 1910. Department of Geology and Natural Resources, State of Indiana.

the drainage is alluvial and Illinois drift. The rating for the basin is 74.

Topography

	Square miles	Protective rating
Level	21,372	100
Rolling	6,584	75
Hilly	4,956	50
Total	32,912	

The average protective value is 87.

PRECIPITATION

This is rated at 91.

Cover

	Square miles	Per cent
Area in woodland	2,896	8.8
Area in pasture	5,562	16.9
Area in crop land	17,740	53.9
All other lands in farms; also cities, railroads, roads, etc	6,714	20.4

The percentages above were found by the use of the data in the census reports of Ohio, Indiana, and Illinois taken from the counties within the Wabash drainage.

	Area in square miles	Protective rating
Woodland	2,896	95
Pasture	5,562	80
Crop land	17,740	55
Excess	6,714	55
Total	32,912	

Average, 62.7.

Average rating for the basin

	Protective rating
Soils	74
Topography	87
Precipitation	91
Cover	62.7
Average	78.7

CRITICAL FOREST AREAS

The critical forest areas of the Wabash are in two distinct districts. The first includes the upland, hilly country in southern Indiana both within and without the unglaciated region. The area within it is highly critical, as the general character of the soil and topography necessitates some sort of protection against the influences

of erosion. In this section the timber was removed from both the valleys and hilltops to make way for agriculture and horticulture and erosion of the hill lands resulted. More and more of this hill country is reverting to wild land each year because of the cityward movement of the population. The area outside the unglaciated region is located principally in Jennings and Ripley Counties. The soil is loessal in character and the streams have cut deep, gorgelike channels into it. In this section it is important that the steep stream banks be protected, since the general level character of the upland makes cultivation possible without much danger of extreme erosion, providing the cultivation is done with care.

There are many streams along which the breaks or bluffs are in an eroding or potentially dangerous condition. Among these may be mentioned Sugar and Racoon Creeks in Parke, Montgomery, and Putnam Counties. Here the country is dissected and rough, with bluffs of 100 to 200 feet in height.

Any further clearing of the woodlands from these areas will assist these streams to cut back farther into the level agricultural plains through which they flow.[7]

The second critical district lies in the flood plain of the Wabash River. From Terre Haute southward it exceeds 5 to 6 miles in width. It has been severely cleared and drained, so that the water now runs off rapidly. As a natural impounding basin it has high possibilities and it is in this section that an artificial reservoir has been suggested. On this flood plain trees along the stream will serve to hold the banks from caving and prevent consequent addition of silt to the flood water. Bluff land along the river should be retained in forest cover.

RECOMMENDATIONS FOR THE WATERSHED

The area that should be retained in forests will make up roughly about one-fifth of the total area of the drainage. It is concentrated in southern Indiana, in the unglaciated region, and on the steep bluffs of the Wabash River and its tributaries where a good forest cover would help to prevent erosion and cutting back into the agricultural plains above. There are also areas in the "flats" of Jennings, Ripley, and Decatur Counties, Ind., which need treatment to check the loss through erosion and rapid run-off; but these are possibly too scattered to warrant public action at present.

The forest areas of the drainage are small, hence the possibility of extensive fires is not high. Where they do occur, however, the destruction of reproduction and litter exposes the soil to erosion. Protection against fires is largely a matter of education in the regions where forest areas are small, and of organization of a State-controlled system to suppress fires in larger areas. Protection is essential.

It has been recommended that planting be used if necessary to insure reproduction on cut-over and cleared areas. Under most conditions, the areas will restock to desirable species if proper care is taken to eliminate grazing. If the areas are neglected, inferior species such as persimmon and sassafras will start. Most of the wood lots in the drainage are grazed, and the solution of this part of the problem will have to depend upon education of farmers.

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[7] Soil Survey of Montgomery County, Ind., p. 6, U. S. Bureau of Soils.

BLACK RIVER BASIN

(Area 24)

DRAINAGE AREA

Two thousand nine hundred and twenty square miles. It extends for about 100 miles in length, with an average width of 25 miles. The watershed is hemmed in between that of the Wisconsin River on the east and the Chippewa on the northwest and embraces Taylor, parts of Clark, Jackson, Trempealeau, and La Crosse Counties. Three divisions of the watershed may be recognized:

(1) The area at the headwaters with rough stony silt loam underlaid by granite and with elevations up to 1,860 feet, forming the divide between the Black, Wisconsin, and Chippewa Rivers. This soil is subject to erosion.

(2) The central portion of comparatively level lands with loamy and sandy soils. This is the largest part of the watershed. The soils are not now eroding, and are not likely to erode badly.

(3) The driftless portion from Black River Falls to the Mississippi River, chiefly northwest of the Black River, is deeply dissected with creeks and ravines. The slopes are readily eroded when deprived of forest or grass cover. The tributaries of the Black River in this part of the watershed are in flood almost every spring after heavy storms.

PRECIPITATION

The mean annual precipitation ranges from 21 to 43 inches. A little more than one-third of the rainfall comes in April, May, and June. As much as 7.9 inches have been recorded at Neillsville in May. The snowfall averages 45 inches at Neillsville and is doubtless heavier at the headwaters. Heavy spring precipitation, and in the northern portion of the drainage area heavy snowfall, is characteristic.

STREAM FLOW

The river is about 140 miles long. It falls 772 feet in this distance or about 5.5 feet per mile. At some points the gradient is steep, being 10, 15, to 19 feet per mile. The banks are high and rocky and lend themselves to the construction of storage dams. The mean annual discharge is 0.72 second-feet per square mile. The maximum discharge recorded is 29,400 (June 6, 1905), and the minimum, 5 second-feet (February, 1918), at Neillsville. The run-off varies from 20 to 50 per cent of the rainfall. In times of flood, when the river becomes swollen, it carries much sediment in the lower part.

FLOODS

The Black River is subject to frequent floods usually in the spring months. The ratio of the maximum flood to mean annual flow at Neillsville is 52.5. This is the highest fluctuation for any river in Wisconsin. Several dams on Black River and its tributaries above Neillsville are used to create a head for power development.

COVER

Forest cover of one kind or another occupies 1,024,000 acres or 55 per cent of the watershed; cultivated land occupies 524,000 acres or 28 per cent, and grassland 321,000 acres or 17 per cent.

(1) The comparatively small section at the headwaters of the Black River is a rough terminal moraine with elevations up to 1,860 feet. The soil is fine sandy or silt loam, originally stocked with hemlock, maple, birch, basswood, and large white pine, with some areas where pine predominated. While this area is the divide between the Wisconsin and Chippewa Rivers, it is also the source of the Black River and will be discussed under this watershed. The virgin stands on this area have been removed by logging operation but second growth of the original species or of birch and aspen where pine once predominated, give fairly adequate cover. Farming has not developed to any extent and the section still finds its most productive use as forest land. Erosion now is negligible, but would grow serious with clearing.

(2) The large central section of the Black River drainage basin is a heavy silt loam in the north, with a transition strip of sandy loam and a considerable area of sandy plain and some swamp to the south. This central section is composed of older glacial material, while the higher soils are outwash material. The heavy silt loam carried forests of hemlock, maple, basswood, oak, some elm, and ash with considerable white pine. The topography here is too gentle for erosion to occur, and a prosperous agricultural district is developing. Wild land has a second growth of hardwoods or aspen and the farming districts contain woodlots, either of culled virgin forest or older second growth. The intermediate soils are of gentle slope or level and have sufficient cover of aspen or oak to prevent erosion. The light soils are level and porous so that there is no erosion, regardless of cover.

(3) The driftless area section is a highly dissected upland with soils of windblown or residual origin. The existing forests are in the form of farm wood lots with oak predominating. As the result of grazing, true forest conditions no longer exist. Erosion is serious, for the soil is readily erodible and cultivation of the slopes furthers it.

RECOMMENDATIONS

From the standpoint of regulating stream flow only the terminal moraine area at the source and the driftless upland section need be considered. The first section would apparently find its highest use as public forest, for its protective influence would be of value on these high slopes. At the same time, since it has an agricultural quality of soil which only topography bars from cultivation, it would be highly productive forest land.

In the driftless upland section, better management of existing wood lots and reforestation of steep slopes will be furthered by extension work and distribution of planting stock under the Clarke-McNary law. One of the chief causes of erosion in this and similar regions is due to the growing of intertilled crops, chiefly corn, on intermediate slopes which should be used for forage crops or pasture.

CHIPPEWA RIVER BASIN

(Area 25)

DRAINAGE AREA

About 9,379 square miles. The basin extends 175 miles from the northern boundary of the State at an elevation of 1,600 feet in Vilas and Iron Counties southwestward to the Mississippi River just above Wabasha, Minn., between the basin of the St. Croix River to the northwest and those of the Wisconsin and Black Rivers to the east and southeast. Its width averages about 60 miles. The whole northern part of the watershed, more than three-fourths of its total area, consists of rolling to nearly level lands with gradual slopes, the variations in elevations being mostly less than 100 feet. The soils vary from fine sands to silt loams and are not subject to erosion.

Within this general area there are several small tracts of 20,000 to 100,000 acres in extent which have rather rough, hilly topography and stony or gravelly soils, most of which are readily permeable and, therefore, not subject to erosion. Lakes are frequent in these areas. These tracts include the western part of the sandy lake and swamp area, the balance of which is on the headwaters of the Wisconsin River; a tract at the head of the West Fork between Hayward and Mellen; several smaller areas south of Hayward as far as the northern edge of Chippewa County and the area forming the divide between the Chippewa, Wisconsin, and Black Rivers, which is discussed as a whole under the River Basin. These lands are unsuited to agricultural development and should be kept in force. In the sandy, gravelly areas, the character of the soil and topography together with the absence of any erosion indicate that surface flow from rains will only occur in unusually heavy rains or in early spring when the ground is frozen.

The southern part of the watershed, chiefly west of Durand and Menomonie and south to the Mississippi River, is in the unglaciated, deeply dissected region of residual wind blown silt loam soils which are subject to erosion and are already seriously eroded on some slopes which have been exposed to washing by the removal of forest and natural grass sod.

PRECIPITATION

The annual precipitation varies from 17 to 44 inches. Over one-third of the rainfall occurs in April, May, and June. A maximum of over 9 inches has been recorded at Eau Claire in June. Winter snowfall amounts to 56 inches in the northern part. The watershed, therefore, has heavy spring rainfall and heavy snowfall in the northern portion.

STREAM FLOW

The Chippewa River includes several large tributaries, namely, the Flambeau, the Jump, the Yellow, the Eau Claire, and the Red Cedar Rivers. The main river has a length of 267 miles. The average discharge is 0.90 second-foot per square mile, or about 8,400 second-feet for the drainage area. The run-off is from 30 to 60 per cent

of the precipitation. The river carries little sediment except in the extreme lower portion where the water becomes turbid from the silt brought in after rains by the tributaries in the driftless area.

FLOODS

Floods occur frequently, usually between March 25 and June 15, and most often in April; a high-water discharge of 66,200 second-feet has been recorded at Chippewa Falls. The ratio of maximum flood to mean annual flow is about 16. Several storage reservoirs have been established on the upper Flambeau and Chippewa Valleys which tend to regulate flood flows. It has been estimated that the flood wave would require 24 days to reach Cairo from the headwaters, 22 days from Chippewa Falls, 18 days from La Crosse, 14 days from Dubuque, 8 days from Keokuk, and 3 days from St. Louis. Reservoirs holding a flood flow equivalent of 11,380 second-feet would only reduce the flood stage at Chippewa Falls by 1.5 feet, at La Crosse by 0.4 foot, at St. Louis by 0.1 foot, and at Cairo by 0.08 foot.

COVER

About 4,091,000 acres, or 68 per cent, of the Chippewa Basin is under forest cover of one kind or another, according to the United States census of 1925; 1,185,000 acres, or 20 per cent, is cultivated; and 727,000 acres, or 12 per cent, is grassland.

The forest land is concentrated in the northern part of the drainage, where 80 to 90 per cent of the area is forested. The original forest of pine and hardwood has been largely cut over and replaced by second growth of aspen, birch, and other hardwoods. About one-half of the area has been burned over in recent years. The central portion of the watershed has 40 to 50 per cent of forest area, also chiefly second-growth aspen and hardwoods. The southern one-third is only about 40 per cent forested. The forests consist chiefly of farm woods, in which oaks predominate with small amounts of basswood, ash, and elm. The more open woods have tough sod of June grass under them.

RECOMMENDATIONS

For the regulation of stream flow, the slopes of the southern driftless section are the critical areas. Already they are eroding and to minimize further damage it is essential that the slopes be maintained in forest and sod cover. Overgrazing which results in cattle trails and subsequent gullying should be prevented. On denuded slopes the forest should be replaced by planting. The small areas of farm woods are not suitable for acquisition as large public forests. Something may be done, however, to encourage the establishment of town and county forests, to distribute planting stock to farmers under the provisions of the Clarke-McNary law and through forest extension education of the owners of such lands. Most of these forests should unquestionably be placed in the protection forest class and maintained.

The rough, stony lands scattered in more or less compact areas around the northern edge of the watershed, although not subject to

erosion, are essentially forest lands and are well suited for acquisition as State or National forests. Fire protection for these areas should be strengthened. Their retention as forests in public ownership will insure the benefits of retarded snow melting and reduced evaporation and avoid the danger of clearing and cultivation for which they are unsuited.

DES MOINES RIVER

(Area 26)

DRAINAGE AREA

Fourteen thousand one hundred and eighty-four square miles. Of this 1,333 square miles are in Minnesota and 12,780 square miles in Iowa, and 71 square miles in Missouri. It is about 350 miles long and 40 to 50 miles wide. It extends in the form of a belt across the west central part of the State in a northwestern to southeastern direction, narrowing to a point in the southeastern corner.

The watershed naturally divides itself into two parts, (1) from the source to Des Moines, the recently glaciated area; and (2) from Des Moines to the mouth, the older glaciated area.

1. The northern portion is characterized by low, rounded swells and shallow basins, numerous sloughs, lakes, ponds, and peat bogs which act as regulators of the flow. The streams flow in narrow, crooked valleys. Some of the lakes have an area of several square miles. The soils are mostly loamy, yet many of them have gravelly subsoils and are readily permeable to water.

2. The southern portion has mature, heavily rolling topography and steep slopes to the banks of all the water courses. These slopes have gradients from 10 to 30 per cent and in the lower part of the drainage basin, may represent as much as 100 to 200 feet difference in elevation between the stream bottom and the level upland. The upland is a series of long, low swells alternating with shallow swales which have sharp stream channels excavated by storm waters. Lakes and swamps are not found in this part of the drainage area. The river itself and its larger tributaries occupy broad, flat-bottomed valleys and meander over well-developed flood plains. The soils are mostly silt loams which originally had a layer of wind-blown material on the surface. On many of the slopes this layer has largely been removed by erosion so that the heavy glacial till is now exposed.

The soils of the bottom lands are variable from fine sands to silt loams and are subject to frequent overflow.

PRECIPITATION

Mean annual precipitation varies from 25 inches in the upper portion to about 32 inches in the lower portion. Snow forms about 3½ inches of the average precipitation for the watershed.

STREAM FLOW AND FLOODS

The river is 550 miles long. This gives a fall of about 1⅗ feet per mile. Near its mouth the river flows in a narrow gorge. The Des Moines River at its junction with the Mississippi has a run-off of

about 0.46 second-foot per square mile, or 20 per cent of the annual rainfall. The river is shallow and is subject to frequent but generally not very severe floods. These occur chiefly in the lower portion of the basin where the abrupt slopes contribute to rapid run-off and the tributaries are subject to freshets.

COVER

Forests occupy 545,000 acres, or 6 per cent of the entire drainage area, lying for the most part in the lower portion of the watershed; cultivated land, 5,810,000 acres, or 64 per cent; and grassland, 2,723,000 acres, or 30 per cent.

In the northern section of the watershed the forest is limited to strips along the streams less than one-half a mile wide. The slopes are occupied chiefly by bur oak, ash, and elm, with cottonwood and willow in the bottoms. The growth in this area reflects the proximity of the prairie.

In the southern section the forests occur along the streams and on the slopes, but occupy a much larger percentage of the area because the mature dissection has left only small proportions of level upland. Black, red, white, and bur oaks, elms, ashes, hickories, and ironwood are the most common species of the uplands. They occur in farm wood lots usually in open stands and except for the extreme southern portion are in the form of isolated small tracts. Most of the woods are pastured and have been heavily culled so that the remaining timber is of poor quality and but small amount of young growth can be seen. The wood lots, when cut clean with the idea of converting them to pasture, have been found to have such poor soil that only a scant growth of palatable grasses comes up.

The bottom lands have a cover of silver maple, willow, and cottonwood on the lowest bench near the stream, and an excellent growth of elms, ashes, black walnut, butternut, and red oaks on the higher benches. These stands have also been culled and more or less pastured, and half of the forest is open in character. There is a heavy weed growth with considerable tree reproduction on the overflow lands.

RECOMMENDATIONS

From the flood-control standpoint, all the forests, both bottom land and upland, should be classed as protection forests because of their effect on erosion and making the banks of the streams secure. The bottom land forest under the State law regarding forests within the meander lines of the streams, are in State ownership. The upland forests because of their occurrence as isolated tracts can not be blocked out in any large units except possibly in the southernmost part of the watershed and, therefore, do not lend themselves to State or Government acquisition. The solution lies in the encouragement of towns and counties in creating public forests wherever it is possible, encouraging the woodlot owners in planting and in maintaining and improving the forests through distribution of planting stock, easement of taxation, and education.

ILLINOIS RIVER BASIN

(Area 27)

DRAINAGE AREA

Twenty-eight thousand two hundred and forty-four square miles. Of this 24,265 square miles are in Illinois, 2,971 square miles in Indiana, and 1,008 in Wisconsin. In the north it extends from Racine County, Wis., as the Des Plaines River Basin, and in the east from St. Joseph County, Ind., as the Kankakee River Basin. Both join the Illinois Basin proper in Grundy County, Ill.

The Des Plaines River drains an area of some 1,425 square miles, of which 1,304 square miles are in Illinois and 121 square miles in Wisconsin. The remainder of the Wisconsin area tributary to the Illinois River is in the Fox River drainage which parallels the Des Plaines River. The Kankakee River drains 5,188 square miles, of which 2,217 square miles are in Illinois and 2,971 square miles in Indiana.

For the purpose of this survey the Illinois River Basin may be divided into two divisions:

1. The watersheds embraced in the Des Plaines and Kankakee Rivers.
2. The watersheds embraced in the Illinois River proper.

ILLINOIS RIVER BASIN PROPER

DRAINAGE AREA

The watershed is nearly level to undulating. It extends from the northeast in a southwesterly direction in the form of a broad belt across the entire State and comprises some of the best farming land in the United States. The greater part of the drainage area is a typical Mississippi Valley prairie region.

PRECIPITATION

The mean annual rainfall varies from 36 to 40 inches. The mean temperature varies from 48° to 52°. Winters are somewhat severe. Ice forms on the streams from ½ to 1 foot thick at times. The average annual snowfall is about 32 inches in the northern section and about 24 inches in the southern section.

STREAM FLOW AND FLOODS

The stream from its beginning at the junction of the Des Plaines and Kankakee Rivers to its mouth at the Mississippi River is some 275 miles long. From the junction of the Des Plaines and Kankakee Rivers to the city of La Salle, Ill., a distance of 50 miles, the fall of the stream is comparatively rapid, dropping about 53 feet. This portion of the river is flanked on either side by bluffs of precipitous rock, rarely more than 2 miles apart. Below La Salle the fall is only 33 feet in 225 miles. The river here is also flanked by bluffs

or hills, but the flood plain is wider. At the lower portion the bottom lands are generally 3 to 4 miles in width. From La Salle to the Mississippi the bottom land subject to flood aggregates about 397,000 acres or 620 square miles.

The maximum discharge of the river at Peoria ranges from 19,000 to 69,000 second-feet, with occasionally as much as 80,000 second-feet. The minimum discharge is from 1,000 to 6,100 second-feet, while the mean annual is from 3,000 to 16,000 second-feet. The run-off varies from 0.4 to 1.2 second-feet per square mile. The run-off is from 24 to 30 per cent of the precipitation, exclusive of the flow from the Illinois and Michigan canals. About half of the bottom-land acreage below La Salle has been leveed at a cost of $30 per acre. The Illinois River is subject to frequent floods. They occur mostly in March and April. During high floods the discharge of the river at Peoria may be as high as 80,000 second-feet. or twice as high as the average maximum flood discharge. The river carries considerable sediment in high water.

COVER

Forests occupy 1,898,000 acres or about 8 per cent of the entire Illinois River Basin; cultivated lands 17,319,000 acres or about 73 per cent; grasslands about 4,508,000 acres or about 19 per cent.

The northern and eastern portions of the Illinois River Basin were always prairie land with the exception of the bottom lands and the bluffs bordering the main stream and its tributaries. The southern portion of the watershed, however, in such counties as Jersey, Greene, Calhoun, Macoupin, Fulton, and Schuyler, formed almost a continuous forest cover with only few interruptions by prairies.

Two types of forest are recognized in the Illinois River watershed—(1) the upland forests and (2) the bottom-land forests.

1. Upland forests are made up of several species of white oak, red and black oak, scrub oak, hickory, elm, ash, hard maple, beech, black walnut, basswood, and others. They occupy 798,000 acres. The upland forests occur on the eroded bluffs of the Illinois River especially between Hennepin and Peoria and on the bluffs of its tributaries. Some of the moraines and other well-drained slopes within the watershed are also covered with forests of this type. The timberlands are thus confined to the rolling and hilly land which is subject to erosion when deprived of the vegetative cover. In Jersey and Calhoun Counties the uplands bordering the Mississippi and Illinois Rivers are still heavily wooded. This is especially true of the abrupt eastern slopes where contiguous belts of forests 50,000 acres in extent may still be found. Some Illinois land orginally covered with timber has been completely ruined through erosion and should have never been deprived of its protective forests.

2. The bottom-land forests contain several species of oaks, soft maple, sycamore, elm, willows, river birch, and cottonwood. The soft maple, cottonwood, and elm make up 84 per cent of the stand. The lowland hardwoods cover 121,000 acres of which about 12,000 acres contain timber of saw-log size.

The greater portion of the bottom lands have now been reclaimed by drainage or levees. Of the entire valley, 77.5 per cent has been

cleared. The building of levees has killed many of the forests by excess flooding, and thus throughout the lower part of the valley forest conditions have been changed by change in water level.

DES PLAINES RIVER

(Area 27a)

The Des Plaines River rises in Racine County, Wis., in what was originally a timber belt, but the main part of the river course runs through an open prairie both in Wisconsin and Illinois. The basin is narrow in the upper part, gradually widening toward the lower portion. In Illinois the valley itself averages about 1 mile wide and consists of a rather shallow trough cut through limestone. This has only a thin covering of glacial drift and the banks of the river are consequently very low. The mean annual rainfall is about 33 inches and the mean temperature about 48°. The winters are somewhat severe. Ice forms from ½ to 1 foot thick on the streams during portions of the winter. The snowfall averages about 36 inches. The Illinois and Michigan Canal and the Chicago Drainage Canal have modified the flow of the river.

KANAKEE RIVER BASIN

(Area 27b)

The Kankakee River rises in St. Joseph County, Ind. The drainage area at the headwaters is a vast swamp with ridges rising here and there and covered with a growth of scrub oak. The swamps act as a regulator by tending to keep up the flow during periods of low water. The swamps in Indiana are being drained, also the channel of the Kankakee is being straightened so that the swamp area will be much reduced in a few years. The part of the watershed in the State of Illinois is flat but well drained and there are no swamps. The river has not cut deep below the surface and the bed is largely of rock. The mean annual rainfall is about 34 inches and the average temperature is about 50°. Winter is comparatively severe, and ice forms on the rivers from ½ to 1 foot thick during portions of the winter. The snowfall averages about 30 inches.

RECOMMENDATIONS

From the standpoint of regulation of stream flow the forest cover need be considered, (1) on the hilly and broken land throughout the Illinois Basin and especially along the bluffs of the Illinois River and its tributaries, and (2) the bottom lands along the Illinois River and its tributaries.

The eroded bluffs along the Illinois River and its tributaries, as well as some of the dissected topography for some distance back from the rivers, are the danger zones in Illinois as far as erosion and rapid run-off are concerned. The bluffs and the slopes of the upland should be maintained permanently in forest cover. The clearing process has gone farther than it should safely go, and the land is now actually in process of gullying or sheet erosion. Although most of

the forests are in small ownership, contiguous forest tracts of several thousand acres along the bluffs are of frequent occurrence. These lend themselves to acquisition either by the State or Federal Government. Counties and towns should be encouraged to establish county or town forests. The policy of distributing planting material to wood-lot owners within the watershed should be liberally pursued. Forest extension with special emphasis on the evils of overgrazing or clear cutting is very essential. Some 221,000 acres of such forest land are classed as protection forests.

On the bottom lands, where they are not leveed, the forests should also be maintained. The State is now considering a plan for purchasing large areas of bottom land along the Illinois River for game refuge and for flood control. Some private organizations are also looking with favor on establishing hunting grounds and game refuges on other parts of these lands. This should be encouraged, as it will serve the double purpose of river protection and game conservation. About 100,000 acres of the forests in bottom land are included in protection forests.

IOWA AND CEDAR RIVERS

(Area 28)

DRAINAGE AREA

Twelve thousand four hundred and ninety-six square miles. Of this, 1,008 square miles are in Minnesota and 11,488 square miles in Iowa. The watershed includes the drainage area of the Cedar River and of its principal tributary, the Iowa River, which join about 30 miles from the Mississippi River. The combined drainage area extends from southern Minnesota for about 250 miles through the eastern central part of the State of Iowa, in the form of a belt about 60 miles wide. It may be divided into two parts, (1) the northern part, extending from the source to Toledo on the Iowa River and Cedar Rapids on the Cedar River—the most poorly drained, recently glaciated section; and (2) the southern part, from a line passing through Toledo and Cedar Rapids to the mouth—a most dissected and older glaciated section.

The northern part is characterized by low, flat swells and sloughs, most of the latter being drained, and small, sluggish, winding creeks. The streams flow in narrow channels between steep banks.

The southern portion is more dissected with heavily rolling topography and steep slopes. There are no lakes or swamps. The soils over the entire watershed are mostly prairie soils of silt-loam character, erodible on slopes, and most heavily eroded in the southern portion, where the loess covering has been largely removed.

PRECIPITATION

The average annual precipitation is about 32½ inches. Depth of snowfall is about 39 inches. Spring precipitation is about one-third of the entire annual precipitation.

STREAM FLOW AND FLOODS

The Cedar River is 300 miles long and has no natural reservoirs and is subject to severe freshets. In Black Hawk County the Cedar River during freshets occupies most of a shallow valley 3 or 5 miles wide. The average annual discharge is 0.59 second-feet per square mile or 25 per cent of the annual precipitation. The streams carry sediment.

COVER

Forests occupy 480,000 acres or 6 per cent of the watershed; cultivated land 5,038,000 acres, or 63 per cent; and grassland 2,479,000 acres, or 31 per cent.

The forest is divided into two types, (1) the upland, and (2) the bottom land.

The upland forests contain oaks, elms, ashes, hickories, and ironwood. They are open in character and are confined to the slopes of the watercourses. They are mostly small areas not contiguous and occurring as wood lots on farms. The woods have usually been heavily culled and are of poor quality. The bottom lands have more or less open forest of silver maple, elm, willow, and cottonwood, with a heavy weed growth on the overflow lands.

RECOMMENDATIONS

The forests within the watershed because of their location will be classed as protection forests. The bottom lands, according to the Iowa forest law, within the meander lines of the streams, are subject to State control. The forests on the slopes, because of their scattered character, do not lend themselves as a general rule to State or Government acquisition, with the possible exception of an area in the vicinity of Iowa City which can probably be blocked out into a practical administrative forest unit.

Encouragement of county or town forests, reforestation by farmers under the Clarke-McNary law, and demonstration of the evils of overcutting and overgrazing, and easement in taxation are the available means for maintaining a permanent forest cover on these areas.

KASKASKIA RIVER BASIN

(Area 29)

DRAINAGE AREA

Five thousand eight hundred and twelve square miles. It extends from the center of Champaign County, Ill., in a southwesterly direction for about 190 miles to the Mississippi River. The basin is long and comparatively narrow. The average width is about 30 miles and the maximum width about 60 miles. The surface is low, level, or undulating, and the gradient of the river is small. The mean elevation of the headwaters is about 740 feet and its mouth is about 350 feet above sea level. The soil is mostly black loam except in the lower portion of the drainage area where it changes

to a yellowish brown clay. The upper part of the watershed is a true prairie with the exception of a forest strip confined to the river banks.

PRECIPITATION

The annual rainfall is about 40 inches. The winters are mild.

STREAM FLOW AND FLOODS

The Kaskaskia is a medium-sized river flowing through a flat region. In certain parts the gradient of the slopes toward the river is as low as 10 feet to the mile, extending for several miles away from the river. Definite bluffs, however, occur where the stream has cut through glacial eminences and river terraces.

North of Carlyle swamp drainage districts are in the process of organization; south of Carlyle few drainage projects have been attempted.

Because of the lowness of its drainage area, the basin affords little ground storage. During wet weather the ground water table rises to the surface. The rains run off, therefore, into the streams very quickly producing very sudden rises and floods. In dry weather as there is little or no ground water stored, the flow of the stream becomes very small and in some places dries up entirely. The banks of the river are low and in times of floods large areas are covered with water, delaying the planting of crops and at times destroying growing crops. The mean annual run-off is 0.74 second-feet per square mile forming 26 per cent of the precipitation.

Flood control in this basin is of considerable importance.

COVER

Forests occupy about 402,000 acres, or 11 per cent of the area of the basin; cultivated land 3,053,000 acres, or 82 per cent; grassland, 265,000 acres, or 7 per cent.

In the northern portion of the watershed about 10 per cent of the area is still in forest, while in the southern portion of the watershed, forest cover forms in some parts more than 20 per cent.

The forest consists of (1) bottom-land hardwoods and (2) upland hardwoods.

1. The bottom-land forest in Kaskaskia watershed occupies some 161,000 acres or about one-quarter of all the good bottom-land timber of the entire State. Near the channel and lower areas elm, soft maple, honey locust, sycamore, and ash are the most common trees. Farther back on the better-drained bottoms pin oak often forms pure stands. The Kaskaskia forests have a higher percentage of ash, hickory, and white oak than the bottom lands of any other drainage basin in the State.

2. The upland slopes which originally were 58 per cent forested now have less than 7 per cent in forests. They are largely made up of post-oak flats and mixed hardwoods on the slopes. Still the forests cover about 241,000 acres.

RECOMMENDATIONS

Most of the upland forests, even on gentle slopes subject to sheet or gully erosion, should be maintained under permanent forest cover. Where the forest can be blocked out in contiguous bodies of 5,000 or 10,000 acres in extent, they should be acquired into State, county, or town ownership and handled as public forests. Where the forests are broken up and are in small tracts, the owners should be encouraged to maintain them in good growing condition, eliminate grazing and clear cutting. To this end the distribution of planting stock provided under the Clarke-McNary law should be liberal among the wood-lot owners. The work of the forest-extension specialist should be concentrated on these areas and the evils of overgrazing resulting in erosion should be demonstrated. Some 145,000 acres of upland forests in the Kaskaskia watershed are classed as protection forests.

The forests on the bottom lands should also be preserved because of their effect of stabilizing the main channel of the river by making the river banks secure against caving in and preventing washing of the bottom lands, and also because of the retarding effect of the forested bottom lands upon the delivery of flood waters toward the Mississippi River. The interest shown in these forested bottom lands by the State and private parties for game refuges may help in their permanent retention. Only a comparatively small acreage of bottom lands in the Kaskaskia River are included in protection forests—5,000 acres. The critical area includes only the lower portion of the watershed because of the dissected topography and liability to erosion. The recommendations, however, apply also to all other forests within the watershed, though to a lesser extent.

MINNESOTA RIVER BASIN

(Area 30)

DRAINAGE AREA

Sixteen thousand two hundred and sixty-four square miles, exclusive of the Little Minnesota River in South Dakota. The Little Minnesota River flows into Big Stone Lake and is a mere mountain torrent whose bed is often entirely dry. For this reason Big Stone Lake is commonly considered the source of the Minnesota River. In this report the area figures given are exclusive of the Little Minnesota River Basin.

The drainage area extends from the eastern slopes of the Dakota foothills nearly across the southern part of Minnesota from west to east for roughly 180 miles in length and 10 miles in width. The watershed as a whole is flat or gently undulating, except for table-land several hundred feet high along the southern border of the basin which forms the divide between the Minnesota and the Des Moines Rivers. Above Mankato the watershed is prairie land, the soil of which is "till," a mixture of sand, clay, and gravel, of glacial origin. Below Mankato the land is also of glacial origin but was originally forested. Now, however, a great part of it is under cultivation, the forests occupying only from one-third to two-thirds of the area.

PRECIPITATION

The precipitation ranges from about 24 inches per year in the upper part to 28 inches in the central and lower part. Winter precipitation in the form of snow is equivalent to 3 inches of rainfall. The snow remains throughout the winter. There is a considerable range in the annual rainfall. The wettest year on record for the upper portion of the watershed was 1905 when the rainfall was about 35 inches. In the central portion of the basin the wettest year occurred in 1903 with a precipitation of 36 inches, and the driest year in 1910, when the precipitation fell to 15 inches. In the lower portion of the basin the wettest year was 1849 when the rainfall was close to 50 inches. The driest year was in 1910 when the precipitation was little over 10 inches. The spring precipitation forms about one-third of the annual rainfall.

STREAM FLOW

The river is about 335 miles long. It falls about 1,250 feet in that distance, and disregarding the first 40 miles which are steep and lie in South Dakota, the fall of the river is on an average of about 1 foot per mile. It rises at an elevation of 1,896 feet above sea level in the northeastern part of Marshall County, S. Dak., and flows southeastward to the State border, where it enters Big Stone Lake, a body of water 26 miles long, 1½ miles wide, and in some places more than 15 feet in depth. In this portion of its course, it is a mere mountain torrent, whose fall in 40 miles is about 950 feet, giving an average slope of 23.7 feet per mile. If this small stream above Big Stone Lake, the Little Minnesota River, is excluded, the mean slope of the Minnesota River is considerably less than that of the Mississippi River. The mean annual discharge near Mankato is from 0.04 to 0.16 second-feet per square mile; the total for the drainage area at Mankato is 1,460 second-feet. The run-off at Mankato is between 15 and 19 per cent of the rainfall; at the mouth it is 24 per cent. The river channel is cut deeply through the prairie. This occurred when a vast lake, known as Lake Agassiz, occupied the northwestern portion of the State and had its outlet through the present valley of the Minnesota River. It was at that time that the abnormally large channel was formed and explains why the river is bordered now by steep slopes or bluffs within a region which otherwise is fairly flat.

COVER

About 1,246,000 acres, or 12 per cent, is under forest cover of one kind or another (including farm wood lots), according to United States census figures of 1925; 6,592,000 acres, or 63 per cent, are cultivated land, and 2,571,000 acres, or 25 per cent, grassland. Most of the forest is near the mouth of the river, in Scott, Le Sueur, and Carver Counties, and a strip along the river as far north as Lac Qui Parle. The forests in the lower portion are largely in the form of scattered farm wood lots and are the reproduction of the original hardwood forests. They are made up of oak, elm, basswood, but-

ternut, and similar trees. The wood lots have been culled and as a general rule heavily grazed, and therefore the natural conditions have been disturbed. The strip along the Minnesota River is made up of two kinds of woods, one along the high bluffs bordering the river and the other of lowland hardwoods of the river valley itself. The upland hardwoods are largely oak, elm, basswood; while the lowland hardwoods are silver maple, river birch, and willows.

RECOMMENDATIONS

From the standpoint of regulation of stream flow, the farm wood lots in the lower portion of the watershed do not constitute an important factor. Although the land is fairly hilly, the soils are not subject to erosion. This is an agricultural section, capable of still further development. Because of the scattered character of the wood lots and the absence of erosion, the forests in this section of the watershed need not be classed as protection forests. Forest extension among the wood-lot owners as to their proper utilization and the absence of great fire danger can be counted upon to retain portions of the farms in wood lots.

The strips of forest land along the bluffs of the Minnesota and the bottom lands of the valley itself present, however, a real source of danger from the standpoint of erosion and stream control. The bluffs rise abruptly to an elevation of from 100 to 400 feet above the river. Since in the western part of the watershed they lie within a prairie section, the forests on the high bluffs are the only natural source of wood material to the farmers. They are therefore being cut heavily. Furthermore, they are being overgrazed, with the result that the slopes are being eroded. If these conditions favoring erosion go much further, the bluffs along the Minnesota River may become even more of a real danger and should therefore be classed as areas that should be ket in forest or in grass. The Minnesota River is subject to severe floods, and the flood danger will still further increase as the slopes along the river become denuded of vegetation. The same is true of the strip of lowland hardwoods close to the banks of the river itself. The forests at the river botton prevent the washing of the bottom-land soil and also help to keep the river banks intact. Although the strip is continuous, it is broken up in small ownerships, and the high value placed on this land (about $20 an acre) makes impracticable the establishment of State or national forests. The problem must be solved in some other way. Counties and townships should be encouraged to establish town or county forests on areas most subject to erosion along this strip. The application of the Clarke-McNary law, under which the Federal Government is cooperating with the States in furnishing planting material to the farmers, should be especially stressed in this region. It may be possible under the present forest tax law to include such lands with cut-over lands, on condition that the owners of land in this strip will refrain from heavy cuttings and overgraving.

MISSISSIPPI RIVER DIRECT, BELOW ST. PAUL

(Area 31)

The watersheds draining direct into the Mississippi River between St. Paul and Cairo form a separate watershed, known as the watershed of the Mississippi direct. It does not form one continuous area, but is in the nature of small river basins directly tributary to the Mississippi River, interrupted by the drainage basins of the larger tributaries of the Mississippi. The description of these watersheds can therefore be most conveniently made by States.

The Mississippi River Basin direct drains an area of some 40,048 square miles, distributed by States as follows:

States	Total area, square miles	Forests		Cultivated land		Grassland	
		1,000 acres	Per cent	1,000 acres	Per cent	1,000 acres	Per cent
Minnesota	6, 486	1, 079	26	2, 284	55	788	19
Wisconsin	3, 652	795	34	958	41	584	25
Iowa	9, 795	877	14	3, 574	57	1, 818	29
Missouri	13, 377	2, 421	28	3, 840	45	2, 300	27
Illinois	6, 738	345	8	2, 846	66	1, 121	26
Total	40, 048	5, 517	22	13, 502	52	6, 611	26

DRAINAGE AREA IN MINNESOTA

The watershed tributary to the Mississippi River in Minnesota embraces an area of some 6,486 square miles. The watersheds of the larger streams emptying directly into the Mississippi River in Minnesota are as follows (proceeding from north to south):

	Square miles
Cannon River	1, 490
Zumbro River	1, 390
Root River	1, 600

A number of smaller river basins are not included, but they lie within the same territory and, therefore, partake of the same characteristics as the three larger rivers mentioned.

The watershed directly tributary to the Mississippi River in Minnesota may be divided into two parts: The southwestern and the northeastern. The southwestern portion forms a part of the glacial soils, while the northeastern portion of the area is within the driftless area. In regard to cover the central and southwestern part of the watershed is prairie land, while the upper portion extending to the western boundary is less than one-third timbered, and the most eastern portion is from one-third to two-thirds timbered. In general, the western and southwestern portions of the watershed contain the uplands and are undulating, while the lower part of the watershed, toward the Mississippi, is deeply cut by the gravel terraced valleys. These watersheds are within the most thickly settled farming section of the State, and by far the greatest part of each drainage area is used for farms.

PRECIPITATION

The annual precipitation shows a slight increase from north to south. The average for the Cannon River is 28 inches; Zumbro River, 28 inches; and Root River, 32 inches. Records of annual precipitation as high as 38 inches and even 45 inches in 1906 on the Cannon River and of 45.4 inches in 1909 on the Root River are available. Of the mean annual precipitation, snow forms from 4.5 to 5 inches.

STREAM FLOW AND FLOODS

The river valleys are narrow and gorgelike, being cut from 200 to 400 feet below the general level. The bordering bluffs rise sharply from the bottom land. Run-off forms from 13 to 29 per cent of the rainfall. Owing to the steepness of the sides of the valley, the rainfall quickly reaches the river. The absence of lakes and reservoirs and deforestation in the lower portions of the drainages result in sudden rises to which the rivers within this watershed are subject. Zumbro River, for instance, in 1888 had a stage of 28 feet above low water; in 1908 it was 20 feet above low water. The Mississippi River, in this portion of its course, is quite clear because Lake Pepin, through which it passes, acts as a settling basin for the eroded material that is brought from the watersheds of the river above.

COVER

About 1,079,000 acres, or 26 per cent, of this watershed are under forest cover, according to United States Census figures of 1925; 2,284,000 acres, or 55 per cent, are cultivated; 788,000 acres, or 19 per cent are grassland.

The forests are almost exclusively hardwoods. The upland hardwoods on the slopes in the driftless area are of oak ash, and elm. Lowland hardwoods on the bottom lands of the Mississippi River are like those described for Wisconsin, being fairly dense stands composed of silver maple, river birch, elm, and willow.

RECOMMENDATIONS

The steep slopes of the eroded driftless area need to be retained in forests to protect them from further erosion. Since they are, however, in the form of scattered farm wood lots, their preservation must depend largely upon the education of their owners. The lowland forests perform a double function. First, they prevent the washing of the bottom lands, and, second, where they extend to the bank of the river channel they protect the banks from abrasion and carving, at least to a certain extent. These forests are inundated several times each year in spring and fall. The bottom lands are now being bought by the Federal Government as a refuge for wild life and most of them should be in public ownership.

DRAINAGE AREA IN WISCONSIN

Some 3,652 square miles of the watershed drain directly into the Mississippi River from the State of Wisconsin. It is made up of the following larger streams (proceeding from south to north):

Chief drainage areas

	Square miles		Square miles
Platt River	320	La Crosse River	485
Grant River	300	Trempealeau River	685
Bad Axe River	150	Buffalo or Beef River	430
Coon Creek	105	Rush River	180

These are all comparatively short and narrow drainage areas, almost wholly within the driftless areas of silt-loam soils of wind-blown origin. The topography consists of high rolling ridge land, intersected with deep ravines and valleys often bordered with precipitous cliffs. The elevation of the ridges above the valleys is 300 to 500 feet. Erosion is everywhere in evidence. The worst erosion which has been observed in the State is in the lower reaches of Buffalo River. Gullies, 10 to 12 feet deep, often extend into cultivated fields.

Another portion of this group includes the alluvial bottom lands and flood plains, chiefly along the Mississippi River itself. They may be up to 4 miles wide. The soils forming them are extremely variable in texture. The topography is generally level with low sand ridges and sloughs. These areas are subject to overflow each year in spring and fall.

PRECIPITATION

The annual precipitation shows a slight increase from north to south. The average at Red Wing is 29.70 inches; at Wabasha, is 28.80; at La Crosse, 31.09; and at Prairie du Chien, 30.86 inches. The range and distribution are about the same for these points, namely, from 19 to 36 inches at Red Wing and at Prairie du Chien from 20 to 45. Over one-third of the precipitation is in April, May, and June. As much as 8 inches in one month, May or June, is on record. There is considerable difference in the amount of snowfall. At Wabasha it is close to 56 inches and at Prairie du Chien only 25 inches.

STREAM FLOW AND FLOODS

The steep gradient of the small tributaries combined with deforestation have resulted in constantly increasing freshets. The current of the Mississippi River averages 3½ miles per hour. The La Crosse River, one of the larger streams for which there are records, has a mean dischage of 300 second-feet and a minimum of 100. The run-off per cent of precipitation is 30 to 35 per cent. The maximum discharge of the La Crosse River is 2,830 second-feet. These rivers at high water all carry considerable sediment, which is deposited to form a soil known as river wash.

COVER

About 795,000 acres, or 34 per cent, of these watersheds are under forest cover, according to United States census figures of 1925; 958,000 acres, or 41 per cent, are cultivated, and 584,000 acres, or 25 per cent, are grassland.

The forests are almost exclusively hardwoods. The upland hardwoods of the slopes in the driftless area are of oak, ash, and elm. The lowland hardwoods are on the bottom lands of the Mississippi River. They are fairly dense, except where broken by grass meadows and sloughs. They are composed of silver maple, river birch, elm, and willow.

RECOMMENDATIONS

The steep slopes of the eroded driftless area need to be retained in forest to protect them from further erosion. Since they are, however, in the form of scattered farm wood lots, their preservation must depend lagely on the education of their owners.

The lowland forests perform a double function; first, they prevent the washing of the bottom lands, and, second, where they extend to the bank of the river channel they protect the bank to a certain extent from abrasion and carving. These forests are inundated several times each year in spring and fall. Such bottom lands are now being bought by the Federal Government as a refuge for wild life, and most of them should be in public ownership.

DRAINAGE AREA IN IOWA

Nine thousand seven hundred and ninety-five square miles. It extends along the eastern part of the State for practically its entire eastern boundary with only two interruptions—at the mouths of the Iowa and Skunk Rivers. It is wide for more than half of its length, from the northern boundary of the State to Davenport, the average width being about 50 miles. From Davenport south to Keokuk it is only from 10 to 20 miles wide.

A strip along the northeastern portion of the watershed is a continuation of the driftless area from Wisconsin and Minnesota. Within this area the larger tributaries flow in rock-walled valleys 100 to 300 feet beneath abrupt bluffs, chiefly formed by the outcropping limestone and 500 to 600 feet beneath the crests of the rounded ridges. The soils are residual wind-blown silt loams, readily subject to erosion and already badly eroded on the slopes. The soil itself is quite impervious and absorbs very little water. The rest of the watershed, although glaciated, is also deeply dissected so that the streams and dry gullies have steep eroded banks and are cut as deeply as 100 or 200 feet below the tops of the undulating uplands. The soils in this area are also loams and silt loams readily subject to erosion and badly eroded along all the water courses. For this section the drainage is so well matured that there are no swamps or lakes. The watershed is drained by a number of small streams, the largest of which are the Upper Iowa River, the Turkey, the Marquoketa, and the Wapsipinicon Rivers.

The flood plain itself is from 1 to 3 miles wide and consists of a series of low benches, bars, and islands intersected by sloughs and swamps back of the levees forming the river channel. The soils are alluvial and extremely variable, and are all subject to overflow. The sides of the valley are bounded by precipitous bluffs rising 300 to 500 feet above the valley floor.

PRECIPITATION

The mean annual precipitation is 32 inches. It increases from the north to the south. Average annual depth of snow is 39 inches. Spring precipitation forms nearly one-third of the total annual precipitation, while winter about one-tenth, and autumn one-fifth of the total.

STREAM FLOW AND FLOODS

The rivers emptying into the Mississippi direct are subject to sudden rises and floods. Practically no stream gaugings of the rivers are available. The stream gradients are steep, particularly where they cut through the limestone rock, the run-off is rapid over the steep slopes and impervious soils, and consequently flood conditions are noticeable every spring and after every heavy rain. The streams carry considerable sediment at all times and noticeably more during freshets. Some of the streams in the driftless area are fed by large springs arising from the underground drainage in the limestone rock.

COVER

Forests occupy about 877,000 acres, or 14 per cent, of the watershed; cultivated lands, 3,574,000 acres, or 57 per cent; and grassland, 1,818,000 acres, or 29 per cent. Originally the watershed was more thoroughly forested than now, due to clearing for cultivation. However, because of the steepness and large areas of the slopes on which the forest occurred cultivation has been confined largely to the rolling uplands which were always treeless. This watershed, together with the lower portion of the Des Moines watershed, is by far the most forested part of the entire State.

The forest cover may be divided into two types, (1) upland hardwoods, and (2) bottom-land hardwoods.

1. The upland hardwoods comprise such species as white, red, bur, and black oaks, elms, ashes, hickories, basswood, and ironwood. By comparison with other parts of the State there are more species in the upland forests of this section than in any other of the watersheds of the State. They are of better quality due in part to the good soils and there are larger areas of commercially exploitable timber. While most of the forest is in small individual ownership, the forests are contiguous over considerable areas, and can be blocked out in units of some 5,000 to 10,000 acres. The forests are being culled and mostly grazed. The more open stands have a natural grass sod and where pastured there is very little young growth.

2. The bottom lands are made up of silver maple, ashes, black walnut, butternut, elms, willow, and cottonwood. The bottom lands in this section are confined largely to the Mississippi River. The higher parts of the bottom lands are cultivated, although the crops are frequently lost by overflow. The river is leveed and the forests within the levees are subject to frequent overflowing. The bottom-land forest is more or less pastured, 30 to 50 per cent of it has been culled, and the remaining stand is open. However, reproduction of the tree species is abundant and is mingled with a dense growth of weeds and vines.

RECOMMENDATIONS

From the standpoint of flood control the forest cover in this watershed is of great importance. Practically all the forests, both on the slopes and bottoms, should be classed as protection forests because of their effect either on erosion, surface run-off, or stabilization of the soil and stream channels. As a matter of fact, the State has passed a law which provides for State ownership of all forests between the meander lines of the streams. Furthermore, this part of the Mississippi bottom lands is included within the upper Mississippi wild life refuge acquisition area. The wooded slopes should also be acquired as far as possible by the State and the Government, and they are of sufficiently large size to be blocked out in practical administrative units.

Furthermore, counties and towns should be encouraged to establish public forests. Reforestation by farmers is desirable and should be given a large impetus by making available cheap planting stock through the cooperation provided by the Clarke-McNary law. Reforestation should be extended not only to the slopes but even to a narrow strip of the uplands to protect the crumbling of the crest where it breaks off from the level upland.

The State has already organized a considerable number of State parks where the forest will be maintained along the bottom lands and in the sections of roughest topography. The State is alive to the importance of these forests as a protection against erosion and places considerable emphasis upon educating the wood-lot owners to the dangers of clear cutting and grazing.

There is a forest tax law in the State under which the wood-lot owners can obtain some easement from taxation provided grazing is eliminated from the wood lots and the forest cover is maintained in good condition. The closeness of these wood lots to a large prairie farming population can incidentally make these protection forests also a source of revenue either to the individual owners or to the State.

DRAINAGE AREAS IN MISSOURI

Some 13,377 square miles of the State drain directly into the Mississippi River in Missouri. This area is divided into two separate watersheds—(1) watershed is drained by such streams as Fabrius, Salt, and Cuirvre Rivers, and (2) the other watershed is drained by Meramec River, Joachim Creek, and other small streams flowing from the west direct into the Mississippi River between St. Louis and Cape Girardeau.

1. The watershed drained by Fabrius, Salt, and Cuivre Rivers comprises some 7,629 square miles, and is roughly rectangular in shape. It constitutes less than 12 per cent of the total State area. The dividing ridge which cuts off this corner of the State and makes it a separate watershed draining into the Mississippi is known as the Grand Divide and forms the boundary line between the Missouri watershed and that of the Mississippi. Most of the watershed is known as flat prairie, consisting of a smooth to gently rolling plain with a gradual slope to the southeast. The streams have cut down through this prairie surface for 25 to 100 feet, forming broad valleys which

give an undulating to gently rolling surface to the plain. As the Mississippi River is approached, the surface becomes hilly and broken and the streams lie deeper in their eroded channels. Here bluffs from 50 to 200 feet high and from one-half to 1 mile apart are found.

PRECIPITATION

Mean annual precipitation is 41 inches, of which about one-third occurs during the spring months. Snowfall in the northeastern part of the watershed is about 25 inches.

STREAM FLOW AND FLOODS

No information is available regarding the streams emptying into the Mississippi River direct except that they are short, subject to floods, and carry considerable sediment. They are not unlike the streams draining the land adjoining the Mississippi on the Illinois side.

COVER

The forest covers about 950,000 acres, or 20 per cent of the entire watershed; cultivated land, 2,369,000 acres, or 48 per cent; and grassland, 1,564,000 acres, or 32 per cent.

The forest is of two kinds, (1) upland hardwoods, and (2) lowland hardwoods. The upland hardwoods on the steeper slopes consist of post oak, small white oaks, pin oak, and black oak. On the lower slopes, with better soils, the upland hardwoods are largely black walnut, large white oak, elm, pawpaw, and basswood.

The lowlands hardwoods are found on the alluvial bottom lands of the Mississippi River and consist of water oak, hickory, cottonwood, silver maple, and sycamore. The forests have been heavily culled over and are extensively used as pasturage.

RECOMMENDATIONS

Since most of the soils on which the upland hardwoods have originally grown are subject to erosion when the ground is broken, all of them, as in Iowa, should be classed under protection forests.

The upland forest for this class occupies some 909,000 acres. They are mostly in the form of broken-up wood lots and do not lend themselves to acquisition for State or Federal ownership. County, town, or municipal ownership, therefore, should be encouraged. Stimulation of forest planting by farmers through liberal distribution of planting material under the Clarke-McNary law should be effected. Forest extension to educate the wood-lot owners as to the dangers of overgrazing and resulting erosion is essential.

The bottomland forests occur largely along the Mississippi River. Retention of much of these bottom lands in forest cover is desirable. The recommendations made for the upland and lowland forests on the Illinois side apply also to the forests on the Missouri side.

2. The area [1] drained by the Meramec River (area 65) and other

[1] That portion of the State lying west of the Cumberland River was purchased from the Indians in the treaty of 1819, and from that receives its name.

streams is about 5,748 square miles. The Meramec River rises in the south-central portion of Missouri, flows northeast, and empties into the Mississippi River near St. Louis. The other streams within this unit, all of them being short, rise on the ridge lying between the Mississippi River and the headwaters of the St. Francis River.

TOPOGRAPHY

The surface is essentially hilly, especially on the upper waters of all streams, but becomes more rolling on their lower reaches as the Mississippi River is approached. The alluvial lands are confined to narrow belts bordering the streams; in few places do they exceed a quarter of a mile in width. The largest areas of level and rolling uplands on the upper waters of the Meramec are on the heads of the intervales between the streams. The most broken sections as a rule are in the immediate vicinity of the larger watercourses where the river hills are cut into steep slopes separated by narrow V-shaped gorges. The prevailing altitudes on the upper waters are from 500 to 700 feet above sea level. About 67 per cent of the area of the unit can be described as very hilly or broken, about 29 per cent of the uplands as rolling or level; about 4 per cent is alluvial.

GEOLOGY AND SOILS

The upland soils are prevailingly residual, derived from the underlying limestones, and are largely silty, though over limited areas these become clays and elsewhere sandy. Over extensive areas, particularly on the upper portion of the Meramec drainage, the surface is covered with a mantle of chert gravel of varying depth. The silty soils, where naked, erode freely, particularly those of loessal origin; the drier soils having more cohesion erode but less freely; the sandy soils which absorb freely erode only slightly. When the blanket of chert fragments is quite thick on the surface it greatly lessens erosion. The Mississippi River Valley lands begin just to the south of this unit.

CLIMATE

The precipitation in this unit, from 50 inches at the southward to about 43 inches at the extreme northward, is of a character which represents the transition from the Gulf type to that of the plains. The Gulf type is marked by approximately equal precipitation somewhat lighter in the fall and in February but heavy during the winter. The plains type is extremely light during the winter and early spring. The snowfall is moderate. The rainfall, while seasonably well distributed, often falls in heavy showers, resulting in local floods in the smaller streams.

HISTORICAL DEVELOPMENT

Practically all of the land on this unit was originally forested. Settlement began near St. Louis, in the early part of the nineteenth century, and rapidly extended along the river. The easily cultivated silty soils near the river were soon largely cleared up. Mining has been extensively developed at the southern end of the unit. Lumbering has been carried on for a long time, but much of the merchantable timber has been removed.

COVER

There are farming communities scattered over all portions of these basins. The heaviest-timbered areas are on the upper waters of the Meramec River in Dent, Crawford, and Washington Counties, Mo. Forests occupy about 1,471,000 acres, or 40 per cent, of the watershed; cultivated lands, 1,471,000 acres, or 40 per cent; and grassland, 736,000 acres, or 20 per cent. In general, the cleared lands are largely limited on the upper waters to certain of the flats on the intervales and to the alluvials along the streams, but on the lower reaches where the uplands are more rolling a large part of the uplands have been put in cultivation. The alluvial lands on the lower part of the Meramec River are subject to flooding and their banks erode most destructively. Upland, where silty and unprotected, especially the silty loess soils, erodes heavily and there are considerable areas of badly eroded lands within the unit.

CONDITION OF FOREST LANDS

Essentially all of the basins of these streams were originally well wooded, with the exception of a few small prairie openings on the Meramec Basin. The forest was largely hardwoods on both uplands and alluvials, but in Washington County of the waters of Big River, and on the headwaters of the Meramec in Iron County and the northern part of Dent County, there is a considerable area occupied by stands of mixed pines and hardwoods. The hardwoods are largely white oak, black oak, and hickory on the uplands, with oaks and gums on the alluvials. The alluvials have been very largely cleared up except where subject to deep and frequent overflow. Of the timbered lands about 20 square miles are located within two State parks on the watershed of the Meramec River. Of all timberlands, about 32 per cent are embraced in wood lots, the remaining lands being held in large bodies by lumber and mining companies. The sites which are now occupied by timber on the whole have rough stony soils, and it is believed that very little change in the future in the forested region will continue to take place.

The larger portion of the lands and sites which are suitable for profitable cultivation have been cleared. On the whole the upland soils can be separated into two distinct classes, those which are residual, derived from the weathering of rocks containing a large amount of insoluble chert which is left as a mantle of stone on the surface, and other soils chiefly of a silty texture which are not stony. The soils which are largely free from chert occupy a broad belt extending down the Mississippi River and taking in a considerably larger part of the lower basin of the Meramec River and a larger part of the basins of all of the other streams to the southward. All of these soils are subject to erosion when naked and situated on slopes, but the silty soils which are free from chert are subject to excessive erosion, since these soils are deficient in cohesion. As a result of this, erosion has been very active on the basins of many of the streams and is a serious problem. The loessal soils of a silty nature, in particular, are subject to most destructive erosion.

CRITICAL AREAS

All of the river hills and bluff lands, especially those along the larger streams which are steepest and which have the longest slopes, should be regarded as critical. In addition all of the loessal soils beginning with the Memphis silt loam at the mouth of the Meramec River and which extend southward in broken bodies, ending with an area of Knox silt loam in the southern and eastern portions of Cape Girardeau County, are critical as well as steeper slopes on silt soils where unprotected by chert at other places on these streams. Many of these areas are too small, however, to be definitely located; but this entire region on account of the character of the soils, the ease with which they are eroded when unprotected either by forest cover, grass, or a mantle of chert, is deserving of the most careful consideration. The hilly topography and shape of the drainage basin of the Meramec River are conducive to heavy floods of the lower stretches of the river. As the flood plain is wide in this section, the floods do considerable damage to other property. The drainage basin of the Meramec River is 110 miles long. It is narrow at the upper end. Its greatest width of 60 miles is near the center, from which it gradually decreases to 10 miles near the mouth. In the lower part of the basin the soil is less hilly but a large part is under cultivation. Although only a few small water powers have been developed, this river has good possibilities for the development of water power. The waters of all these streams in times of flood bear a high silt burden which is poured directly into the Mississippi River. The same is true of other flood waters on account of their immediate proximity to the Mississippi. Their flood waters are emptied without possibility of diffusion. On account of their small size, however, the proportion which they contribute is extremely small.

RECOMMENDATIONS

There should be a great extension of the area of public forests on the upper waters of the Meramec River and its tributaries. These lands are well situated for the purpose on account of their non-agricultural character. Through the medium of county agents and other local agencies individual land owners should receive instruction in methods of handling agricultural land so as to reduce erosion of soil to a minimum. Except on the headwaters of the Meramec the forest fire problem is not a serious one, since the remaining forest lands are largely held in wood lots. It is desirable that better protection of the larger tracts be taken care of, possibly through an increased appropriation under Section 2 of the Clarke-McNary Act. There are certain small areas of land which is very steep and now in cultivation on which erosion is excessive which should either be planted to grass and maintained in permanent soil, or which preferably should be planted to trees.

DRAINAGE AREA IN ILLINOIS

About 6,738 square miles. It forms a narrow strip varying in width from 3 to 55 miles along the western boundary of the State, and extends for 650 miles. Approximately one-fourth of the entire length of the Mississippi borders Illinois.

The watershed consists of two physiographic features—(1) level bottom lands along the flood plain and (2) very dissected uplands, which terminate on the western side facing the river in abrupt bluffs.

The soils on the bottomlands are very variable, but usually approach clays in the southern part, and sands in the northern. The uplands are for the most part covered with glacial drift. The exceptions to this are in the extreme northwestern part of Jo Daviess County and a part of Calhoun County, and in the southernmost portion of the watershed below the mouth of the Big Muddy. But whether glaciated or not, they have a top layer of loess which is windblown soil. Such soil is not readily erodible unless found on rough topography.

The bluffs along the entire river rise in an almost continuous belt. In Jo Daviess County the dissected country lies farthest from the bank—about 18 miles, while in the rest of the belt the dissected topography is confined to a narrow belt usually of not over 6 miles in width.

PRECIPITATION

The difference in latitude between the extremes of the State is more than 5°. The mean annual temperature at Cairo (58° F.) averages 10° F. warmer than that a Dubuque (48°). The mean annual rain fall at Cairo (41.6 inches) averages 6.6 inches greater than that at Dubuque (35 inches).

STREAM FLOW AND FLOODS

The streams emptying into the Mississippi direct are short and the gradient steep. They carry considerable sediment. The bottom lands are covered with sediment brought from the higher slopes. The streams are subject to sudden rises.

COVER

The forest occupies about 345,000 acres, or 8 per cent; cultivated land about 2,846,000 acres, or 66 per cent; grass land 1,121,000 acres, or 26 per cent. The forests are divided according to the physiography of the watershed into (1) upland hardwoods—these occur as belts along the steeper slopes—and (2) bottom land hardwoods covering the bottom lands along the Mississippi River.

(1) The upland forests extend as a belt of heavily wooded bluffs from Alexander County north to the northern boundary of Monroe County for a distance of more than 100 miles with scarcely a break. Between Monroe and Jersey Counties the slopes are commonly cleared and the forests form disconnected strips along the slopes. Above Jersey and Calhoun Counties the forests on the slopes form again a continuous belt. Between Calhoun and Jo Daviess Counties the forests are fragmentary and the slopes of the uplands are less precipitous giving a less pronounced relief. They are made up of oaks and similar hardwood species. The upland forests occupy about 260,000 acres.

(2) Bottom lands extend from the southern end of Union County to the Wisconsin border. There is approximately 553,350 acres of bottom land on the Illinois side. The forests occupy only about 15 per cent of total bottom land or about 85,000 acres. In the southern part of the State the bottom lands on the Illinois side are from 3 to 4 miles wide. In the northern three counties—Whiteside, Carroll, and Jo Daviess—the bottom lands on the Illinois side are narrower than in the south. They average about a mile from the bluffs to the river in Jo Daviess County, and widen out to 3 miles in Whiteside County. The bottom-land forests are confined to the southern extension of the river. They are found in the central portion and occur again in the northern portion. Since most of the river is leveed, the bulk of the bottom-land forests are found next to the bluffs. The stands outside the levees are the remnants of the original bottom-land forests. In their virgin state these forests were heavy stands of ash, elm, hackberry, soft maple, honey locust, and gum. Logging, however, has left very little of the original forest. Inside the levees there is usually a strip of willow, cottonwood, sycamore, and soft maple. The width of this strip is rarely more than one-half mile. The forests within the levees are subjected to frequent flooding. Under such conditions willow, cottonwood, and sycamore show abnormally rapid growth.

RECOMMENDATIONS

From the standpoint of flood control, the forest cover in this watershed is of great importance. Practically all the forests, both on the slopes and bottoms, should be classed as protection forests because of their effect either on erosion, surface run-off, or stabilization of the soil and stream channels. The wooded slopes, where they form contiguous bodies of thousands of acres in extent, should be acquired by the State or Federal Government. The forest policy of the State provides for the purchase of such wooded slopes in the southern part of the watershed for State forests. Where the wooded slopes are broken up, as they are in the northern part of the watershed, counties and towns should be encouraged to establish public forests. Planting by farmers on those wooded slopes should be encouraged by a liberal distribution of planting stock. The wood-lot owners should be educated to the dangers of clear cutting and grazing on the slopes.

Some of the bottom lands as far south as Rock Island are within the upper Mississippi wild-life acquisition area. More of these bottom lands should be publicly owned, either by the State or Federal Government, especially by the War Department, as a factor in controlling floods on the middle course of the Mississippi River.

BIG MUDDY RIVER BASIN

(Area 31a)

DRAINAGE AREA

Two thousand four hundred and two square miles. It lies in southern Illinois and is elliptical in shape, being 70 miles long and 50 miles wide. The watershed is nearly flat, with a clay loam soil.

It lies within a partially wooded region, the forest cover increasing in amount toward the mouth of the river where it occupies in some places as high as 73 per cent of the area.

PRECIPITATION

The mean annual fainfall is about 42 inches. The winters are mild. Ice does not form very thick and as a rule the snowfall is light and lasts but a short while.

STREAM FLOW AND FLOODS

The gradient of the river is small. Its sources are about 710 feet above sea level and its mouth about 310 feet. The mean annual run-off is 0.77 second-feet per square mile and forms about 26 per cent of the mean annual precipitation.

The banks and bed of the stream are soft and insecure. The stream is subject to extremes of high floods and very low water. In some places the high water overflows the land on each bank for 2 or 3 miles. Some sections resemble a lake during floods. Backwater from the Mississippi frequently extends up the Big Muddy River for a distance of 60 miles and floods reach the height of 30 feet above low water.

COVER

Forests occupy about 434,000 acres or about 28 per cent of the basin; cultivated land about 875,000 acres or 57 per cent, and grass-lands about 228,000 acres or 15 per cent.

A large portion of the Big Muddy River Basin was originally forested. Even to-day the upper part of the watershed has a forest cover between 10 and 15 per cent and in the lower portion over 25 per cent of the land is in forest.

The forest belongs to two types—(1) the upland hardwoods and (2) the bottom-land hardwoods.

(1) A large part of the upland forest is composed of post-oak flats and the slopes are covered with the usual upland hardwood species.

(2) The bottom lands, compared with the size of the stream, are disproportionately large. About 73 per cent of the bottom lands are forested and the forest area seems to be increasing in these bottoms.

RECOMMENDATIONS

Most of the upland forests, even on gentle slopes, are subject to sheet or gully erosion and should be maintained as permanent forest cover. Where the forest can be blocked out in contiguous bodies of 5,000 or 10,000 acres in extent they should be acquired into State, county, or town ownership and handled as public forests. Where the forests are broken up and are in small tracts the owners should be encouraged to maintain them in good growing condition, eliminate grazing and clear cutting. To this end the distribution of planting stock provided under the Clarke-McNary law should be liberal among the woodlot owners. The work of the forest extension specialist

should be concentrated on these areas and the evils of overgrazing resulting in erosion should be pointed out. Some 127,000 acres of upland forests in the Big Muddy watershed are classed as protection forests.

The forests on the bottom lands should also be preserved because of their effect of stabilizing the main channel of the river, making the river banks secure against caving in, preventing washing of the bottom lands, and also because of the retarding effect of the forested bottom lands upon the delivery of flood waters toward the Mississippi River. The interest shown in these forested bottom lands by the State and private parties for game refuges may help in their permanent retention. In addition, in the Big Muddy watershed, the coal industry is well developed on the bottom lands. The timber has a high merchantable value and the forests form a source of revenue to the owner. Their utilization, if it is properly done, need not interfere with their protective value. The mining industry, therefore, may also assist in the permanent maintenance of the forest as an essential part of their business. Although the Big Muddy watershed is about half the size of the Kaskaskia watershed, it has practically the same area of forest and nearly three times as large areas of bottom-land forests. Some 13,000 acres of these bottom-land forests are classed as protection forests.

MISSISSIPPI RIVER DIRECT, ABOVE ST. PAUL

(Area 32)

DRAINAGE AREA

The drainage area of the Mississippi above St. Paul, exclusive of the Minnesota River, covers 20,449 square miles (13,087,000 acres). It extends from the northeastern part of Becker County, across the central part of Minnesota from northwest to southeast, roughly for about 225 miles, and has a width from 110 to 150 miles.

The watershed may be divided into two parts: (1) The upper portion, north of line drawn diagonally through Douglas, Stevens, Meeker, McLeod, Sibley, Le Sueur, Rice and Dakota Counties, is a region that was originally either entirely or largely covered with a forest of pine, spruce, fir, tamarack, and white cedar. This section also abounds in lakes and swamps. (2) The lower portion, south of this diagonal line, is a region which originally was largely covered with forest of hardwoods, oaks, elm, hickory, ash, butternut, and black walnut. In the southwestern border of this section are some stretches of prairie land.

The entire watershed is covered with a drift sheet, ranging in thickness from 100 to 300 feet. The surface of this drift sheet forms a somewhat undulating plan with comparatively slight irregularities which form long low swells and hollows. Many of the depressions have no outlets and to them are due the multitude of swamps and lakes in the basin. Within the upper portion of the watershed there are vast stretches of deep, sandy soils. These, together with the large number of lakes and swamps, form a natural surface and underground reservoir. In the lower portion of the watershed the soils are largely till, not subject to erosion.

PRECIPITATION

Precipitation varies in different parts of the basin. The mean annual rainfall decreases from 30 inches in the extreme southeastern part of the watershed to 24 inches in the western part. The mean annual rainfall for the entire basin is about 27 inches, of which 3 to 4 inches occurs as snow and remains during the winter months. The spring precipitation is 7.3 inches. In the upper part of the basin, the wettest year occurred in 1905, when the rainfall was about 37 inches, and the driest year in 1910, when the precipitation fell to 17½ inches. In the southern part of the watershed, the wettest year occurred in 1849, with a rainfall of some 50 inches, and the driest in 1910, with a precipitation of 10 inches.

STREAM FLOW

The upper Mississippi River drains the greater part of Minnesota and is the most important stream in the State of Minnesota. The stream is about 530 miles long from its source to St. Paul. It falls 750 feet in that distance, or at the rate of about 1.4 feet per mile. The discharge at St. Paul varies from 0.12 to 0.53 second feet per square mile. The total mean annual drainage for the entire area at St. Paul varies from 4,290 to 19,000 second feet. The run-off is between 9 and 24 per cent of the rainfall. The silt carried by the river is negligible.

FLOODS

The upper Mississippi Basin above St. Paul is subject to floods, chiefly in the spring, but these floods are less frequent and occur later than those of the lower river. The floods of the upper Mississippi, which are generally caused by heavy rains, are sometimes augmented by the melting snows accompanying decided thaws, and at other times by ice gorges. The floods occur as a general rule during the months of April, May, and June, although on at least two occasions since 1880 floods occurred in October.

Besides the large number of lakes and swamps which act as natural reservoirs, there is a reservoir system operated by the United States Engineer Corps. There are six reservoirs in the system. Their surface at high and low water and their capacity is given below.

Storage reservoirs in upper Mississippi Valley, surface area

Reservoir	High	Low	Capacity
	Square miles	*Square miles*	*Cubic feet*
Winnibigoshish	161	117	45,000,000,000
Leech Lake	224	173	30,000,000,000
Pokegama	45	24	4,700,000,000
Pine River	24	18	7,500,000,000
Sandy Lake	16	8	3,158,000,000
Gull Lake	30	28	4,910,100,000
Total			95,268,100,000

Although the reservoirs are operated chiefly in the interest of navigation, they also have a beneficial effect on water power and flood control. Furthermore, on some of the tributaries of the upper

Mississippi, such as the Crow Wing River and Rum River, there are both natural and logging dams which control the water in the stream. For Rum River, Lake Mille Lacs forms a natural reservoir and tends to equalize its flow.

COVER

About 7,357,000 acres,[1] or 56 per cent of the watershed, is under forest cover of one kind or another, according to United States census figures of 1925, and 4,160,000 acres, or 32 per cent, is cultivated, and 1,570,000 acres, or 12 per cent, in grassland. Of the total area 8,245,000 acres, or 63 per cent, is in the upper part of the watershed within the coniferous type, 4,188,000 acres, or 32 per cent, is in the lower portion of the watershed within the hardwood type, and 654,000 acres, or 5 per cent, is prairie. The northern part of the upper Mississippi watershed was originally the great red pine and white pine forests of Minnesota, while the swamps contained black spruce, white cedar, tamarack, and balsam fir. Most of this forest has been cut over, so that not more than 3 per cent of the virgin forest still remains. The cut-over land has been repeatedly burned, but very little land has been entirely denuded, as the ground becomes quickly overgrown with popple (aspen), jack pine, or if repeatedly burned by shrub growth. In this coniferous area over three-quarters of the land is still in forest. This is a region which does not lend itself to agricultural development on a large scale and will forever remain a forest region.

RECOMMENDATIONS

Flat topography, the large area of swamps and lakes, large areas of deep sandy soils, and the absence of erosion make the forest cover in this portion of the watershed, from the standpoint of stream regulation, of secondary importance. This is a region which is now being protected against fire, and the passage of the forest tax law may induce large owners of forest land to take better care of it and hold it for future timber crops.

The only areas that need to be considered in connection with stream-flow control are the swamp forests along certain tributaries of the Mississippi which may be considered of importance and classed as storage areas. Of these the Crow Wing River is one of the more important ones. It is fed by bogs in northeastern Wadena County, west central Cass County, and southeastern Hubbard County. These swamps or bogs are natural reservoirs and should be left as they are. Very little of this area has been drained as yet. The Crow Wing River and similar tributaries are being developed for water power and a great deal of the land has been bought up by power companies. It is possible that these companies might be interested in keeping their lands maintained in forest cover as a storage basin. These tributaries, on account of their topographical features, are, however, good storage reservoirs, regardless of whether or not there is any timber on them. It is a flat country, and a forest located on the

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[1] The areas of the watersheds were obtained by planimetering and expressed in square miles. The areas of land in forests, under cultivation, and in grasslands were obtained from different sources, but largely from United States census figures.

These areas of forests and other kinds of land, when expressed in per cent of the area of each watershed, may differ somewhat from the actual acreage obtained from other sources. These differences are less than 1 per cent in all cases.

watershed of such tributaries would not necessarily be a protection forest. The recommendation regarding these storage forests is merely more intensified protection against fire, under the application of the Clarke-McNary law, but no public acquisition.

On the lower portion of the upper Mississippi watershed the forest is largely in the form of hardwood remnants of the original virgin forest. It is being culled over for the better timber and used to a large extent as pasturage for cattle. As this region is being agriculturally developed and lends itself to greater agricultural development, and since, further, the wood lots are scattered and in small ownership and the soil does not show signs of excessive erosion, they need not be considered as protection forests. Forest extension, as to the proper utilization of the wood lot, can take care to a large extent of maintaining a portion of this land in continual forest cover.

The trees along the banks of the Mississippi River above St. Paul differ from the alluvial bottom-land hardwoods found farther south. The clumps of willow and river birch can hardly be said to form a forest and serve their minor rôle here of keeping the banks intact.

ROCK RIVER BASIN

(Area 33)

DRAINAGE AREA

Ten thousand seven hundred and sixty-five square miles. Of this 5,444 square miles are in Wisconsin and 5,321 square miles in Illinois. It extends from the southeastern part of Wisconsin into the northwestern part of Illinois. The watershed is irregular in shape and is about 175 miles in length and 85 miles in greatest width.

The drainage area of the Rock River in Wisconsin is naturally divided into the eastern or glaciated section and the western or driftless section drained by the Sugar and Pecatonica Rivers which enter the Rock River inside the Illinois State boundary.

1. The eastern section contains 3,730 square miles and is a region of low rolling hills with considerable swamp land and many lakes. The pot-hole topography of the limestone formation is unfavorable for run-off. The soils are heavy but often underlain with gravel. While some erosion occurs, it is not serious.

2. The western section contains 1,714 square miles and is an unglaciated upland, deeply dissected by numerous streams and ravines. The soils are loams of residual or wind blown origin and easily eroded. There are no lakes or swamps to hold moisture.

The Illinois portion of the watershed has, on the whole, comparatively gentle topography. The eastern tributaries rise in an area of swamps and lakes most of which have now been drained. The soils are largely sands and gravels.

PRECIPITATION

The annual precipitation ranges from 20 to 44 inches with one-third of the precipitation coming in April, May, and June. Winter precipitation in the form of snow averages 37 inches. As much as 10.2 inches of rainfall in one month, in May, has been recorded.

The winters in the northern part of the basin are severe; the snowfall is heavy and ice forms a foot or more in thickness on the streams. In the lower part of the basin the winters are somewhat mild.

STREAM FLOW AND FLOODS

The average slope of the Rock River is a little over 1 foot per mile. The annual discharge at Rockton is from 0.64 to 0.86 second-feet per mile. The run-off is about 28 per cent of the precipitation. The maximum discharge ranges from 15,000 to 27,000 second-feet. There has been a gradual diminution in the flow of the river. The river is not subject to extreme flood conditions.

COVER

The forests occupy 826,000 acres or 12 per cent of the entire watershed; cultivated lands about 3,927,000 acres or 57 per cent; grassland 2,137,000 acres or 31 per cent. The Wisconsin or upper portion of the watershed is much more wooded than the southern or Illinois portion. The Wisconsin portion of the watershed comprises 700,000 acres of forest or 20 per cent of the watershed; forests occupy some 126,000 acres or less than 4 per cent of the Illinois portion of the basin.

Much of the cultivated land in the Rock River drainage basin was never covered with forest as it was prairie land. The original forest of the watershed was cut over and much of it cleared for agriculture. What still remains is in the form of scattered wood lots which have been repeatedly culled over and heavily grazed so that true forest conditions no longer exist. The present forest cover does not exceed one-third of the land area in any county and in some cases is less than 2 per cent.

The forest is of the upland type, composed chiefly of oak, basswood, and ash. The only conifer is tamarack, which makes some fair stands in the eastern part of the upper drainage basin.

RECOMMENDATIONS

Since the entire watershed is a highly developed agricultural region and had originally a great deal of open prairie land, and since the land of a large portion is of gentle topography and made up of soils not readily erodible, the forests as a rule need not be classed as protection forests here. The only portion of the watershed that deserves consideration from the standpoint of erosion is the western third which falls within the driftless area in Wisconsin. This unglaciated section is similar to the driftless area of the Wisconsin River watershed. It is deeply dissected by numerous streams and ravines and the slopes are easily eroded. The maintenance of a forest or grass cover is necessary to prevent further erosion.

The problem of retaining a forest cover on these slopes, just as in the corresponding part of the Wisconsin watershed, lies in the creation of county and town forests, assistance to farmers in forest planting, better utilization of forest products, and education of the farmers as to the danger of erosion. The lands in need of forest cover are the steeper slopes unsuited for cultivation.

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SKUNK RIVER

(Area 34)

DRAINAGE AREA

Four thousand three hundred twenty-three square miles. The topography is very similar to that of the lower portions of the Iowa and Cedar Rivers on one hand, and the Des Moines on the other, although its source lies just within the recently glaciated, poorly drained area of central Iowa.

STREAM FLOW AND FLOODS

The watershed is about 170 miles long and about 25 miles wide. The stream is flanked with slopes which are subject to erosion and are badly eroded in the lower portion of the drainage area. The river and its tributaries are subject to freshets and the run-off of the river at Augusta is 0.55 second-foot per square mile or 23 per cent of the annual precipitation. It carries a large load of sediment after every heavy rain.

COVER

Forests occupy 245,000 acres or 9 per cent of the watershed; cultivated land 1,718,000 acres or 62 per cent; and grassland 804,000 acres or 29 per cent.

The forests, both of the upland and lowland type, are the same as in the Iowa or Des Moines watersheds. The forests are in the nature of isolated farm wood lots, heavily culled and grazed.

RECOMMENDATIONS

All wooded slopes and bottom lands within this watershed are distinctly protection forests. Most of the bottom lands come under the State law providing for public control of forests within the meander lines of streams. The small size and the character of the wood lots on the slopes do not lend themselves to State or Government acquisition. If they are to remain in permanent forest cover, as they should, the owners themselves must be encouraged by the State and county in doing so, through easement in taxation, distribution of planting stock, and forest extension.

ST. CROIX RIVER BASIN

(Area 35)

DRAINAGE AREA

The drainage area of the St. Croix River is 7,664 square miles. Of this, 3,553 square miles are in Minnesota and 4,111 square miles in Wisconsin. The drainage area forms a triangle, with the broad base at the north and the apex at Hastings, Minn., or Prescott, Wis. The St. Croix River itself forms the boundary between Wisconsin and Minnesota.

The watershed may be divided into two parts. The upper part corresponds to the original white pine-red pine forests of the north, and the southern and smaller part to the upland hardwood type. The boundary between the two follows a diagonal line from the northeastern part of Isanti County to Rush City, then following along the river to Taylors Falls in Minnesota or St. Croix Falls in Wisconsin, thence diagonally to the southeastern boundary of the watershed in the center of St. Croix County, Wis., toward Eau Claire.

The northern portion abounds in lakes and swamps. On the Wisconsin side of the watershed the lakes are more numerous than in Minnesota. Many of the lakes in Wisconsin are without surface outlet, and many others have been dammed to control the outflowing stream for logging. In the Minnesota portion the lakes comprise less than 1 per cent of the area, and a less number of these lakes are controlled by dams. The soils in the upper portion of the watershed in eastern Minnesota and western Wisconsin are loamy and not readily eroded, except for an area in Minnesota in eastern Pine County. This includes the territory of the streams draining into the St. Croix River east of Kettle River. Here the topography is very rough, with many rapid streams, and would be subject to erosion if the forest cover were removed.

The lower portion of the St. Croix watershed lies within the oak timber belt. The topography is rolling and hilly, with few lakes or swamps. The soils in the southernmost part of the watershed are heavy limey soils, and are somewhat subject to erosion if the cover on the slopes is broken.

PRECIPITATION

The annual precipitation for the basin is 31 inches of which 3½ inches falls as snow. Over one-third falls in April, May, and June. The average annual snowfall varies from 45 to 52 inches. Monthly precipitation as high as 11 inches has been recorded at Osceola in June. The heavy spring and early summer precipitation, particularly northward, is characteristic.

STREAM FLOW

The river is about 170 miles long and falls 344 feet in that distance; for the upper part at the rate of 3 feet per mile. The discharge at the mouth is from 0.4 to 1 second-foot per square mile. The total mean discharge for the whole watershed varies from 2,500 to 6,000 second-feet. The run-off is from 30 to 40 per cent of the precipitation. The St. Croix River flows for the most part between high bluffs of gravel or rock. This is also true of tributary streams within the watershed which have cut through the drift and into the underlying rock. In the case of the Kettle River, tributary to the St. Croix River in Minnesota, the river has cut through the drift and into the sandstone which yields water from the many springs found along the river. The river carries little sediment and is only rarely turbid.

FLOODS

The St. Croix River is subject to floods, most commonly in April and less often in March, May, and June. Under flood conditions the discharge may be as high as 35,800 second-feet.

COVER

According to the United States census figures of 1925, about 3,384,000 acres, or 69 per cent of the St. Croix drainage area, have a forest cover, 1,030,000 acres, or 21 per cent, are cultivated, 491,000 acres, or 10 per cent, are grassland.

The forests of the upper portion of the watershed still cover more than two-thirds of the land area. Although the original forest is practically gone, the second growth is in evidence almost everywhere. The sandy plains came up to jack pine and, where fires have been frequent, to a low growth of sweet fern, blueberries, and grasses, forming a tough sod. The loamy soils, which formerly supported a heavy stand of white pine, are now covered with aspen and birch second growth. The swamps of the upper watershed are characterized by spruce, tamarack, and cedar trees, and still retain more or less their virgin conditions. The loamy soils at the southern portion of the watershed have a mixed hardwood forest of oaks, basswood, elm, and maple, mostly in the form of farm woods. On the whole, the present natural cover, whether second growth, grass, or low shrubs, is effective in holding the soil from erosion.

RECOMMENDATIONS

From the standpoint of flood control, the area in eastern Pine County within the watersheds of the streams draining into the St. Croix River east from the Kettle River is most important. Because of the roughness of the land here, the rapidity of the streams, and also because of fires and the use of the wood lots for pasturage, there is evidence of serious erosion. The greater portion of this area is in forest cover at the present time. Where fires are kept out and the land not used for pasturage, this territory will soon come back to natural forest conditions representing maximum efficiency in erosion control. About 70 per cent of this area should remain in forest.

The rest of the watershed does not present any problem and no public acquisition of land for the regulation of stream flow is necessary. The sandy plains in Wisconsin form an excellent natural reservoir, irrespective of cover. Their low value for farming and the increasing demand for jack-pine pulpwood make it probable that they will be used for growing timber crops.

The loamy soils are being cleared and farmed, a development which will continue and extend. In the absence of erosion, the maintenance of a forest cover is not essential, although forest cover for the land on the steeper slopes is desirable for reasons other than the regulation of stream flow.

The southernmost end of the lower portion of the watershed, comprising the silt-loam soils in St. Croix County, contains some small

tracts on the steeper slopes which should be protected by the maintenance of forest cover. They are too small for Federal or State acquisition. They should be acquired as far as possible for county or town forests. Since they are parts of farms, the proper handling of the slopes should be further brought about through forest extension in the use of the land and the owners should be assisted in planting under the Clarke-McNary law.

WISCONSIN RIVER BASIN

(Area 36)

DRAINAGE AREA

Eleven thousand nine hundred and three square miles. It extends from the Michigan boundary south and then west in a belt through the center of the State, roughly 225 miles long by 50 miles wide. The watershed may be divided into four parts:

(1) The northern lake and swamp section:

The upper portion south to Tomahawk is gently rolling, with differences in elevation rarely exceeding 100 feet. It has over 100 lakes and many swamps. The soils are predominantly sandy and deep, and noneroding. Considerable areas of rough stony land are also included in this part of the watershed but are not subject to erosion.

(2) The northern heavy-soil section:

From Tomahawk to Wisconsin Rapids the land is rolling, with loam and silt-loam soils and few lakes or swamps. Erosion is negligible at present.

(3) The central sandy flat section:

From Wisconsin Rapids to Portage the river passes through a flat sand plain region with large areas of swamps on either side. The swamps are partially drained and include most of the State drainage districts.

(4) The driftless section:

Below Merrimack to the Mississippi River at Prairie du Chien, the land is deeply dissected with steep slopes along all the tributaries. The soils are silt loam of wind-blown origin, easily erodible and in process of more or less serious erosion. Lakes and swamps are absent. The wooded slopes are largely covered with a tough sod of June grass, which prevents erosion. Once, however, the sod is broken, the slopes are readily eroded. Dry coulees become torrents after rains and carry material up to boulder size. Within this portion of the watershed is found by far the most serious erosion.

PRECIPITATION

The annual precipitation ranges from 23 to 40 inches. About one-fourth of the precipitation occurs in the spring. Winter precipitation in the form of snow in the northern part averages over 50 inches. As much as 9.7 inches of rain in the month of May has been recorded. The watershed is characterized, therefore, by heavy spring precipitation and in the northern portion by heavy snowfall.

STREAM FLOW

The river is about 430 miles long. It falls 1,046 feet in that distance or at the rate of 2½ feet per mile. The average annual discharge at the mouth is about 0.86 second-foot per square mile. The total for the drainage area is 10,250 second-feet. The run-off is between 30 and 40 per cent of the rainfall. For two-thirds of its length, the river carries only slight quantities of sediment. Toward the mouth the stream becomes very turbid during high water and carries much sediment (amount undetermined).

FLOODS

The Wisconsin River is subject to frequent floods. They generally occur in April, May, and June, although the worst flood on record occurred in October, 1911. On the tributaries within the driftless area, floods occur after every heavy rainstorm. During high floods the discharge of the river may amount to 72,000 second-feet. The ratio of the maximum flood to mean annual flow at Nekoosa, over half way up the river, is 12. The flow is regulated by several storage reservoirs toward the headwaters.

COVER

About 4,630,000 acres, or 61 per cent of the watershed is under forest cover of one kind or another, according to United States census figures of 1925; 1,850,000 acres, or 24 per cent is cultivated; 1,138,000 acres, or 15 per cent is grassland. Most of the forest area is in the upper fourth of the watershed where forest occupies from 80 to 95 per cent. The middle portions have 40 to 60 per cent forest. In the driftless area 35 to 45 per cent is wooded.

By types the forest is divided as follows:

The northern lake portion has jack pine on the sandy lands, aspen and mixed hardwoods on the heavier soils, and spruce, cedar, and tamarack in the swamps.

The northern heavy-soil section of the watershed is covered by forests of hemlock and hardwood or second growth of hardwood or aspen and birch.

The central sandy section is covered with jack pine and scrub oak. The swamps are open and grassy.

The forest of the driftless section is in the form of farm woods of oak, with small proportions of ash, elm, and butternut. These woodlots are remnants of the original forest, and where they have not been overgrazed they still retain their virgin condition of ground cover.

Along the bottoms of the larger streams there is a characteristic forest of silver maple, elm, and river birch.

The area of virgin forest which remains does not exceed 2 per cent, except the swamp forests, many of which still retain their original cover conditions. Although the forests have been cut over and most of them burned over the land has not been denuded except where cleared for farming. The young forest growth which comes up is as effective in preventing erosion as the old growth, although its storage capacity is less.

RECOMMENDATIONS

From the standpoint of regulation of stream flow only the northern lake and the driftless sections need be considered. The northern heavy soil section will develop as farms and because of its favorable topography and absence of erosion will not be a menace even if cleared. The central sandy section although not suitable for farming forms a natural underground storage reservoir with its deep sands and large swampy areas, regardless of forest cover. Agriculture is declining, and owing to the presence of large paper mills the area is likely to be devoted to growing jack-pine timber.

The northern lake section, because of its large areas of lakes and swamps, is a natural reservoir and has been further improved by artificial storage reservoirs. The function of the forest, and especially that of the coniferous forest, is largely the retardation of snow melting. It is part of the great recreational region of the Mississippi Valley and is distinctly a forest region and should remain so. Aside from fire protection, which should still be strengthened, there is no necessity for public acquisition of the swamp land for the regulation of stream flow. On the other hand, the large areas of rough land in this region, because of their dissected topography and the influence of the forest cover in converting surface run-off into seepage, should be classed as protection forests and should be in State or national ownership.

The driftless section of the watershed is by far the most important for stream flow regulation. The steep slopes, broken topography, soils easily eroded when deprived of vegetative cover, the large per cent of cultivated land, the large load of sediment carried by this section of the stream all tend to make it a dangerous area. The solution lies in the maintenance of the steeper slopes in timber and replacing the forest on those slopes already denudued and the prevention of overgrazing in the woodland pastures. The difficulty of accomplishment is further increased by the fact that the forest is broken up into small wood lots, rarely continuous for as much as a square mile. It does not, therefore, lend itself to public acquisition, either National or State. Most of the forests of the section are protection forests. As a general policy the counties and towns in the section should be encouraged to establish county and town forests. These will cover only small areas. In addition the provisions of the Clarke-McNary law for distribution of planting stock to farmers and forest extension should be applied specifically and liberally to that section. The fire hazard is small, and no special fire protection measures are necessary.

To further encourage the farmer in maintaining a good forest cover on the slopes and keeping his wood lot in good growing condition, better methods of wood utilization in connection with the existing wood-using industries should be taught. It may be further desirable to amend the existing forest tax law to provide easement of taxation to those wood-lot owners who would be willing to handle their wood lots effectively by eliminating grazing and clear cutting. Such provision is already incorporated in the present forest tax law, except that it permits grazing in the wood lots.

BAYOU TALLAHALA

(Area 37)

LOCATION AND AREA

The Bayou Tallahala is a comparatively small river in southwest Mississippi, flowing directly into the Mississippi River. Its basin occupies 1,046 square miles and lies to the south of and immediately adjacent to the watershed of the Big Black River. The drainages of the Pearl and Homochitto Rivers form its east and south boundaries, respectively, although the southern boundary nearest the Mississippi River adjoins a relatively small area which drains directly into the Mississippi River.

TOPOGRAPHY

This basin is fairly well drained; the topography is rolling to hilly, sloping generally westward toward the Mississippi River. The northern and western 53 per cent of the watershed is a sparsely settled, rugged country. East of these hills the country is rolling in character and comprises a prosperous agricultural section.

The elevation of the Tallahala Basin ranges from 500 feet near its eastern limit to slightly below 100 feet where it touches the Mississippi River. The average elevation is about 275 feet.

The larger streams in this area have moderately swift currents, although the smaller tributaries, especially in the hill country, flow more rapidly than do the larger streams and therefore are more actively cutting down their beds. Stream beds are free from rocks and stony material, nothing larger than gravel being present. The bottom lands vary from one-fourth mile wide along tributaries to 1 to 3 miles wide along the Bayou Tallahala. Like the adjoining basins, this area is an important one from the standpoint of soil erosion. The western part of the watershed is, of course, the most critical area because there both soil and topographic conditions combine to produce high susceptibility to erosion. Fortunately there has been less clearing of land for agricultural purposes in this region than in the eastern part of the watershed.

The roughly triangular shape of this drainage basin, and the fan-like arrangement of the main tributaries, make for exceptionally favorable conditions as regards quick collection and discharge of run-off.

The slopes near the divide are cut in every direction by large, swiftly flowing streams and their tributaries. Past erosion has left much of the region too hilly for agriculture, and here, fortunately, thousands of acres of land have been left in forest. Wherever the forest has been removed erosion is still very active.

GEOLOGY AND SOILS

The Bayou Tallahala watershed lies entirely within the Mississippi bluffs and silt loam uplands soil regions. The commonest soils of the bluff region are characterized by a typical brown, silty material, believed to be of wind-blown origin, the parent beds of which origi-

nally were sand banks or bars in the Mississippi River. During dry seasons prevailing southwesterly winds picked up these soil particles and deposited them to the east of the Mississippi River. The deposits are deepest near the Mississippi River where weathering has produced the characteristically perpendicular bluffs found all along the western boundary of the region. These loess soils grow shallower to the east, finally feathering out and giving way to the sandier soils of the Upper Coastal Plain.

The underlying soils are composed of Coastal Plain deposits, and are found at a depth of 40 or 50 feet below the surface of the ground along the western border of the bluffs.

Memphis silt loam is the predominating soil type of the watershed. It is peculiar in its drainage features, acting in this respect like an impervious clay. It absorbs water so slowly that ponds for watering cattle are formed simply by building a small dam across a depression. Such ponds, losing more by evaporation than by absorption, will retain water for a long period of time. When rain falls there is a substantial and rapid run-off, which causes washing; and large areas of this soil type have been so dissected by such washing that they are beyond practical reclamation. Much of this soil type would undoubtedly be benefited by tile drainage. Open ditches are beneficial on level areas, where, owing to the tendency of soil to stand in vertical banks, they do not fill as rapidly as in other soil types.

On steeply inclined surfaces lack of humus, shallow plowing, absence of terraces, and ridge cultivation combine to accelerate the denudation of the fields.

CLIMATE

The mean annual precipitation is about 53 inches, half of which falls during the warm season from April to September, inclusive. The average rainfall during March, April, and May is about 15 inches. In 1927 about 17 inches fell during March and April. In comparison with the other areas in the Southern States within the Mississippi watershed the normal precipitation in this district may be regarded as rather heavy; the rating for this factor has been set at 55.

The mean temperature is about 68° F. for the year; 45°–50° for January and above 80° for July. Snowfall is insignificant, occurring on the average of one day per year.

HISTORICAL DEVELOPMENT

Originally this entire drainage was heavily forested. Settlement commenced between 1810 and 1820. At present approximately 790 square miles, of the total of 1,046 square miles, are in farm ownership. Some 348 square miles, or about 33 per cent of the total area, is in woods and forest. Four-fifths of this area is in farm wood lots.

Two forested types are represented in the drainage; bottom land hardwoods in the westernmost 1 per cent and pine in the remainder. The 15 square miles within the boundaries of the bottom land hardwood type are about 50 per cent in forest, 29 per cent unimproved,

and 21 per cent in cultivation. The total bottom land area is limited in extent; it is flat and low, and of little importance from the standpoint of erosion and flood control.

Thirty-three per cent of the 1,031 square miles within the boundaries of the pine type is in forest, 45 per cent is unimproved, and 22 per cent is cultivated. The cultivated land is of necessity somewhat concentrated toward the east, where the topography is more favorable for farming; but to a considerable extent in the east and to a very great extent in the west, injudicious land clearing and improper methods of agriculture have resulted in excessive erosion and the abandonment of many fields. About four-fifths of the area in woods and forest is in farm wood lots. Forest areas are scattered, lessening somewhat their effectiveness in preventing erosion and run-off, but improving the possibilities for control of fire.

CONDITION OF LANDS OTHER THAN FORESTS

In the bottomlands, the 21 per cent of land in cultivation is mostly in cotton, corn, and cane, all intertilled or "open" crops; but the flatness of the land precludes any serious erosion. In the uplands, formerly in pine, the principal crops are corn, cotton, and truck. Except for absolutely essential contour plowing, effective steps are rarely taken to prevent erosion.

It has been, and in some places, still is, customary to clear land and cultivate it until the soil becomes impoverished. When the soil became exhausted the field was abandoned; then more land was cleared, and the process was repeated. This "laissez-faire" system of farming, employed by many farmers over a period of several decades, has resulted in extensive abandonment of land. Much of this cleared land slopes steeply and therefore is especially susceptible to erosion. To-day, thousands of acres of deeply gullied fields, barren, or covered by scrub pines, stand as a monument to this wasteful practice.

Ridge cultivation, in vogue for the last 50 years, is generally employed. This method of cultivation, together with the tenant system of farming, is causing thousands of acres of uplands to erode beyond reclamation.

Marked changes and improvements in agricultural methods must be made before the improved land, especially that in the western part of the pine region, can exert a proper influence in preventing run-off and erosion.

Of the lands neither in cultivation nor in forest, a considerable part is in bare, eroded slopes; and much of the rest is in brush, scattered young pines, or grass and weeds of varying and often insufficient density. With the exception of the bottom lands these areas are grazed without control, and burned annually or at intervals of a few years. The unimproved area in the bottom lands includes some swamp. Throughout the pine region and especially in the western part thereof, the cover on the unimproved land has a very low protective value; 60 has been taken as a fair rating for this class in the pine region as a whole.

CONDITION OF FOREST

The bottom-land hardwoods type contains gums, moisture-loving oaks, and some cypress. Although part of the area classed as forest has been logged, it still supports an adequate forest cover, especially where cutting was more or less on a selection system. Saplings and underbrush are frequently rank. This forest type, because of its location, exerts practically no effect on erosion and run-off.

The pine type includes short-leaf and some loblolly pine, pure, or mixed with upland oaks and hickories and other hardwoods, and with nearly pure long-leaf pine occurring over much of the southeastern third of the area. Great areas were cleared for agriculture during early settlement and the wooded area has been decreasing ever since. In places which would have come back naturally to forest, clear cutting for lumber or farm materials, together with severe erosion and almost annual fires, has prevented the growth of anything but brush. Litter and humus, light and shallow at best in the South, have been almost entirely destroyed by the frequent burning. The forest area in the pine region as a whole is rated at only 80, in contrast with a rating of 95 in the bottom-land hardwood forest.

To sum up, the forest throughout the pine type is not of maximum efficiency as a cover, and the cover as a whole is in poor condition. The total cover for the entire drainage is rated at only 72; more complete information might cause it to be put even lower.

CRITICAL AREAS

Most of the western portion of this watershed lying within the boundaries of the pine type is in the aggregate a critical area, with a negative cover influence. The average protective value for the entire watershed has been computed to be 64. The rugged topography, character of soil, and prevalence of heavy rain storms during certain parts of the year combine to make this region extremely susceptible to erosion. The extent of worn-out fields, gullied beyond reclamation, is witness to the need of some adequate remedy if these lands are to be conserved for future use. Agriculture could well be continued on areas least susceptible to erosion, but the greater part of the region is best suited for tree growth. Forests would assure a productive crop from these lands, and at the same time would give protection to the bottom lands by preventing excessive soil wash and by equalizing the flow of streams.

RECOMMENDATIONS

The area indicated as critical might well form a portion of a national forest purchase unit; but more explicit information, such as is obtained by the National Forest Reservation Commission, will be necessary before specific recommendations are made.

Undoubtedly a considerable proportion of this watershed should always remain in forest; the establishment of a State forest here would help attain this end. As it seems rather doubtful, however, that State action will take place within the near future, it is recommended that steps be taken to thoroughly investigate the possibilities for the establishment of national forests here.

Whether public forest areas are established here or not, the common practice of burning the woods must be abolished. Large scale planting will be necessary to bring back a forest cover to areas denuded by erosion, and steps should be taken at once to develop the technique necessary for this difficult but highly important task. Regulated system of harvesting the timber crop by keeping some forest cover continuously on the ground will undoubtedly be found essential. Specific Federal aid might advisably be granted the State in fire protection and planting in this area, working through the State department of forestry.

BIG BLACK RIVER

(Area 38)

LOCATION AND AREA

The Big Black River Basin, occupying 3,559 square miles in west central Mississippi, lies south and east of the Yazoo bottom lands and highlands. The drainages of the Pearl and Tombigbee Rivers form the eastern and part of the southern boundaries. The small remaining portion of the southern boundary is formed by the Tallahala watershed.

TOPOGRAPHY

The drainage basin extends about 150 miles in a northeast and southwest direction, and varies little from an average of 25 miles in width over its entire length. By far the greater part of this watershed is well-drained, rolling to hilly country. The basin as a whole slopes gently toward the southwest. The flood plain of the Big Black forms a long, narrow strip of flat bottom land, which extends through the central part of the watershed and covers 14 per cent of the total area. Sixteen per cent of the area, limited to the eastern extremity of the watershed, lies within rolling country. The remaining 70 per cent is classified as hill country, the southwestern end of it located in the steep, badly eroded lands of the Mississippi bluffs proper. The elevation above sea level ranges from 75 to 80 feet, where the Big Black joins the Mississippi River, to slightly over 500 feet at the upper end of the watershed; the average elevation is about 300 feet.

The Big Black River and its major tributaries are, for the most part, sluggish, and they meander considerably as they approach the Mississippi River. Headwater streams are moderately swift, and they are cutting down their beds more rapidly than are the streams of the lower country.

The flood plain of the Big Black River forms a strip of densely forested level land which varies from 1 to 3 miles in width. The river and its larger tributaries frequently overflow the bottom land. Their channels are deep, crooked, and much obstructed by forest débris. There is little sand in the channels except along the short branches originating in the more hilly sections, and nowhere is there any rock. When at flood height all of these streams carry much yellowish silt; the deposition of this silt on low, forested

lands has obliterated many old channels; also it has materially improved the lowland soils, thus compensating somewhat for the injury caused in many places by the excessive erosion of the river system.

GEOLOGY AND SOILS

Practically the entire watershed of the Big Black River falls within the Mississippi bluffs and silt loam uplands soil regions.

Alluvial soils are of course predominant in the flood plain of the Big Black River itself.

The narrow belt of the Mississippi bluffs along the western end of the watershed is made up of heavy deposits of loess soil. It is the general opinion of geologists that this formation had its origin in sand bars along the Mississippi River from which the finest particles were picked up by prevailing southwesterly winds and deposited to the east of the river; this phenomenon still persists in a minor degree. The deepest deposits of loess are found along the western border of the region; they become progressively thinner to the east, where they finally give way to the sandier loams of the coastal plain sedimentary deposits.

The fineness of the soil particles in the loess formation and a tendency toward vertical lines of weakness make this soil extremely susceptible to erosion. This tendency to washing, combined with the rugged topography of most of the area, makes the region extremely important from the viewpoint of soil conservation. Deep, sheer gullies are common throughout the entire region, where a sufficient vegetative cover has not been maintained. Every rain deepens these gullies and extends their courses farther up the slopes. The minor slopes also are subject to erosion, and extensive tracts have been rendered unfit for cultivation.

CLIMATE

The mean annual precipitation on this watershed is about 50 inches. It is slightly greater over the higland at the upper part of the basin, becoming less nearer the mouth of the river. As on the other minor drainage areas to the south, half of the annual precipitation comes during the warm half of the year, and about 15 inches normally comes during March, April, and May. In 1927 about 22 inches fell in March and April. In comparison with other Southern States, the normal precipitation may be regarded as medium. Rains, however, frequently come in torrents and cause considerable damage to the uplands by washing away the soil and to the lowlands by flooding.

The mean temperature is about 65° F. for the year, 45° for January and above 80° for July. Snowfall occurs on an average of two or three days each year.

HISTORICAL DEVELOPMENT

The Big Black River drainage is primarily agricultural, 62 per cent of the area being in farms. Originally the region was almost wholly forested. The first settlements were made about 1812. Of the entire drainage of 3,559 square miles approximately 35 per cent (1,251 square miles) is at present in woodland and forest, 38 per cent

(1,363 square miles) in unimproved land, and 27 per cent (945 square miles) under cultivation. Forest property is scattered, 60 per cent being in farm wood lots.

Approximately 17 per cent of the watershed falls within the range of the bottom land hardwoods type. This type occurs along the main river as a long, narrow strip which runs down the middle of the area and expands to entirely cover the watershed at the lower end. Of the remaining 83 per cent, 36 per cent lies to the northwest in what is nominally the upland type, and 47 per cent to the southeast, in the pine type. Actually, both upland types are transitional, containing shortleaf and some loblolly pine, in varying mixture with oaks, hickories, and other hardwoods. The bottom land, hardwood type, is made up mainly of gums, oaks, and cypress. Abuse of both farms and forest has reduced the cover rating of the drainage to 70.

CONDITION OF LAND OTHER THAN FOREST

Corn and cotton are the principal farm crops. Both are intertilled, a factor which is of no great importance in the level bottoms and on the benches, but which on the slopes contributes considerably to erosion. Contour plowing is almost universal on all except level land, and terracing is practiced to some extent. The cultivated land is rated at 90 in the bottoms and at 70 within the boundaries of the upland hardwood and pine types.

The Big Black drainage contains much land recently dropped from cultivation, together with older abandoned lands, brushy areas, and some practically denuded land which never has been cultivated. There is a tendency for pine to come in on old fields and cut-over land, but this is largely offset by annual, or nearly annual, fires. Natural revegetation is impossible on seriously eroded land. The reestablishment of a suitable ground cover and soil binder can probably best be attained by planting to trees. The unimproved lands, as as whole, except those which lie in the lowlands and rate 75, are poorly protected against erosion and run-off; they rate at 55 and 60 in the pine and upland hardwood types, respectively.

CONDITION OF FORESTS

Along the upper benches, the bottom land, hardwood type, consists of oaks, gums, and cypress, has largely been cleared for agriculture, but some virgin timber still remains on many of the lower lands immediately bordering the Big Black and its more sluggish tributaries. About 44 per cent of the land within the boundaries of the type is still in forest. The cover rating of this bottom land hardwood forest is high, 90, but its area, 263 square miles, is only 7 per cent of the entire drainage, and its location makes it of little importance as a flood-control area.

The forests on the uplands have been classed arbitrarily as pine to the southeast of the river and as upland hardwoods to the northwest. Actually both types are mixtures of upland oaks, hickories, and associated hardwoods, with varying quantities of loblolly and shortleaf pine; the pines form an increasingly large proportion of the stand toward the south, and in places occur in pure stands. The greater part of clearing has been for agriculture; logging, where

practiced, has been generally destructive; clear-cutting, followed by burning, has resulted in the bare or brushy areas of unimproved land described above. Many woodlots have been culled for farm timbers and logs for the market as well as for firewood, but still constitute forest cover. Woods fires are common and in many places annual; they reduce the stand and destroy the scanty litter characteristic of southern upland types. Grazing, although common, seems to have little effect on the forests. The forests in both pine and upland hardwoods types, besides being too much reduced in area, are below their potential protective effectiveness, and are rated at 75.

CRITICAL AREAS

All of this watershed with the exception of the bottom lands along the main streams and a small area of relatively flat country in the upper part of the basin is a critical area. Aggressive protective measures are necessary if excessive wash is to be prevented. In the past, agricultural practice has generally failed to employ these measures, with the result that in the aggregate an enormous amount of top soil has been washed away and thousands of acres have been actually abandoned. The average rating of the protective value of this watershed has been put at 66. The continuance or reestablishment of a forest cover is the means by which a great part of these lands can be used most advantageously in the future. Forest planting and regulated cutting practices, together with protection from fire, will best serve to attain this end.

RECOMMENDATIONS

Certain parts of this watershed should be in public ownership if the general productivity and value of the soil for protective purposes is to be restored and maintained. Proper land use within the drainage will not only necessitate the reestablishment of a forest cover on large areas of land which already have been rendered useless for agricultural purposes, but also the maintenance of a forest cover on those forested areas which are either too rough or too easily eroded for cultivation. It is believed that a forest cover can best be maintained or restored through the establishment of national or State forests. It is doubtful, however, that any such potential public forests lie entirely within this watershed, since similar areas, with which they would undoubtedly tie in, adjoin in the Yazoo Highlands to the north and in the Bayou Tallahala watershed to the south.

There is also the ever-present need to obtain through education and extension work better agricultural practices and fire-prevention measures. This can be brought about through cooperation of county agricultural agents, extension foresters, and the State forestry department. Effects of soil wash can be mitigated by plowing in such a way as to fill incipient gullies; with the subsequent establishment of a grass cover, grazing may be possible. Steep slopes which are still in forest should be allowed to remain so. The most severe washes should be seeded up with black locust and honeysuckle or other tree and brush species which are found to best serve this purpose. Bermuda grass and Japanese clover (*Lespedeza*) also can be used to advantage

in holding and reestablishing soil cover. Much experimental work must be done to determine the effects of forest cover on soil erosion, the best silvicultural practices for this region, and especially the means of establishing forest cover on eroded areas. This should be handled by the Federal or State agencies best equipped for carrying on such investigations.

HOMOCHITTO RIVER

(Area 39)

LOCATION AND AREA

The Homochitto River Basin, located in southern Mississippi, covers an area of approximately 1,261 square miles. The Bayou Tallahala drainage and a small portion of an area draining directly into the Mississippi form its northern boundary. The Pearl River Basin and the drainage basins of several streams flowing into Lake Pontchartrain lie just to the east and southeast. The remainder of the southern boundary is formed by another small area draining directly into the Mississippi River.

TOPOGRAPHY

This basin comprises a well-drained, rolling to hilly country. Twenty-four per cent of the watershed is classified as hilly, this area being near the western end of the basin. Just west of the hills and extending down to the mouth of the river is a broad expanse of flat land subject to overflow. In all, the flat lands comprise 14 per cent of the entire basin, the remaining 62 per cent is rolling land.

The general slope of this basin is to the southwest toward the Mississippi River to the point where the Homochitto enters it, which is about 14 miles north of the Louisiana State line.

The elevation of this watershed ranges from approximately 70 feet above sea level where it meets the Mississippi River to 500 feet at its eastern extremity, with an average elevation of 250 feet.

Streams are sluggish to moderately swift in character with swifter streams found near the headwaters and in the hills. Stream beds are composed of sand or silt, no rock being present. Along the streams are bottoms with undulating areas adjoining. The hill country lies within the Mississippi Bluff region, where most of the slopes are too steep to be suitable for tillage. Among the more gentle slopes and the crests of the wider ridges there are areas less gullied and broken that can be used for agriculture.

The general outline of this basin is fan-shaped, making conditions especially favorable for the quick collection and discharge of run-off.

The greatest concentration of agricultural development has taken place in the eastern part of the watershed, where the country is less rugged and the soils are less subject to destructive erosion.

GEOLOGY AND SOILS

The greater part of this drainage area lies within the Mississippi Bluff and Silt Loam Upland soil region. An extension of the Upper Coastal Plain enters the south central part of the watershed in Frank-

lin and Amite Counties, comprising possibly one-seventh of the watershed area.

The loess soils found over the greater part of this basin have been formed from fine, wind-carried particles supposedly transported from ancient sedimentary beds in the Mississippi River. The deposits are deepest along the western edge of the region where weathering has developed a series of high, vertical bluffs following along within a few miles of the Mississippi River. Toward the eastern part of this drainage area the loess soils become thinner and give way finally to the sandy sedimentary loams of the Coastal Plain. Coastal Plain sediments form the underlying deposits in all the Bluff region, the line of demarcation between the two soil types being very sharp and distinct.

Due to the fineness of the soil particles and the rugged nature of the topography, erosion is at its worst in the loess country. Among the most striking topographic features are the erosion forms upon the slopes of some of the hills. Many slopes have been so dissected and eroded as to present the appearance of mountains in miniature.

CLIMATE

The mean annual precipitation is about 55 inches, approximately half of which falls during the warm season of the year, and 15 inches during March, April, and May. In 1927 about 18 inches fell during March and April. The normal precipitation here may be regarded as heavy.

The mean temperature is about 60° F. for the year, 45°–50° for January and above 80° for July. Snowfall is insignificant, occurring on the average but one day per year.

In this region, heavy downpours lasting from 3 to 10 hours occur at times, and as much as 4 to 6 inches of rain may fall in one such storm, causing much erosion and gullying.

HISTORICAL DEVELOPMENT

Agriculture is the principal activity of this drainage area. The first extensive settlements were made by the English between 1763 and 1779.

Of the 1,261 square miles in the area, originally almost all forested, there are estimated to be at present (1927) 38 per cent (484 square miles) in woodland and forest, 50 per cent (624 square miles) in unimproved land, and 12 per cent (153 square miles) in cultivated land. About seven-tenths of the forested area is in farm wood lots. About 14 per cent (174 square miles) of the drainage, at the mouth of the river, lies within the boundaries of the bottom land hardwood type; the remainder is upland and largely in pine. Of this upland, the western part, more hilly and more easily eroded, is also the more heavily forested, while the eastern part is more extensively cultivated.

In the past, much land has been cleared and farmed which should have been left in forest, and other land, which would have remained productive under adequate agricultural treatment, has been eroded and lost through mismanagement. Much of the abandoned agricul-

tural land has been eroded too rapidly to permit natural revegetation, and, since no effort has been made to reproduce a cover crop by artificial means, these lands have become a nonabsorptive catchment basin for heavy rains, as well as a constant source of silt. Most of the other unimproved lands, as well as practically all the forest, burn annually or at frequent intervals, thus lowering greatly their productive value. The rating for the entire cover on the drainage as a whole has been put at 72.

CONDITION OF LANDS OTHER THAN FOREST

Cotton, corn, and some truck constitute the principal crops. On the level bottoms and on some of the more nearly level uplands these intertilled crops do not constitute a detrimental influence, but on the rolling and hilly lands, especially on the very erodible bluff soils to the west, they accelerate serious washing of plowed land. Contour plowing is necessarily almost universally practiced, but terracing and other more intensive means of arresting erosion seem to be little used.

The type of agriculture which for a long period of years has been followed in this region and which is still practiced by the great majority tends to deplete the soil by robbing it of its organic matter. The ground is bare of vegetative cover for long periods each year, thereby allowing the fields to erode and be cut up with ravines and gullies. Shallow plowing (3 to 4 inches) and ridge cultivation are practiced extensively.

The rating for all the cultivated land in the drainage is 82, a figure determined principally by the predominating upland soil with its rating of 80.

The unimproved lands include a large aggregate acreage recently dropped from cultivation, similar areas abandoned years ago, and much logged-off land which has never been farmed. On the actual gullies of the abandoned fields little or no vegetation has established itself naturally, and the grass, weeds, and pines which have come in between gullies have not ordinarily been sufficient to prevent further encroachment of erosion. On other rolling or hilly areas, where erosion had not already begun, frequent fires have wiped out much pine reproduction and have decreased the protective effect of the cover to such a point that erosion is now commencing. The cover is rated at 80 on the unimproved land in the westernmost 14 per cent of the drainage and at 60 on the unimproved land in the remaining higher ground within the pine-type borders.

CONDITION OF FORESTS

Two types occur within this drainage; bottom-land hardwoods in the western one-seventh of the region and pine in the remainder. The bottom-land type consists principally of red gum, tupelo gum, oaks, and cypress. The pine type in the western half of the uplands, which includes the hilliest part of the drainage, is made up of shortleaf and loblolly pines in mixture with upland oaks, hickories, and other hardwoods; in the eastern half, where the country is rolling, long-leaf pine occurs, in places forming pure stands. The area within the pine type as a whole contains some 413 square miles

of forest, concentrated somewhat toward the west. The common logging practice has been to cut the land clear of timber, leaving an inadequate protective cover to the soil. Erosion begins before the pines can reestablish themselves or before any but a sparse cover of grass or brush has had an opportunity to come in. Once begun on such cut-over areas, erosion in this country is extremely difficult to control. Annual or nearly annual fires burning over wooded and cut-over land alike have greatly decreased the effectiveness of the vegetative cover. Little accumulations are prevented, and the humus has been burned out of the top soil to such an extent that its effectiveness as a retainer of soil moisture has been impaired, as well as its effectiveness in retarding surface-water flow and erosion.

The wooded and forest area in the pine type is rated at 80, in contrast with 95 for the smaller and less significantly located bottom-land hardwood forest near the mouth of the river. The effectiveness of the existing forest cover in erosion and flood control could and should be greatly increased through fire protection and regulating cutting practices, and the forest area should be extended.

CRITICAL AREAS

With the exception of the bottom lands near the Mississippi River and a strip along the eastern edge of the watershed, which together comprise one-third of the entire basin, the remainder is considered as a critical area. Because of the rough topography, highly erodible soil, and the common occurrence of numerous torrential rains during certain periods of the year, great quantities of soil have already been washed away by the streams of this region following the clearing of land for agriculture. This has gone on to such a degree that a considerable area has been rendered worthless for agriculture and can only be brought back to a state of productivity by the reestablishment of a forest cover.

The average rating of the protective value of this watershed has been placed at 64.

RECOMMENDATIONS

State or national forests, with a vigorous program of erosion control, should be established on the most severely damaged portions of this watershed. Part of this region has already been inspected and recommended as a purchase area by a member of the National Forest Reservation Commission. Not only should the Government point the way by taking under control the reestablishment of a cover on these worn-out lands, but it should also seek through education and demonstrations to guide the agricultural landowners in this region into practicing methods of tilling the soil which will result in a more conservative use of the land. Through conservative cutting practices and careful logging, a forest should be preserved on the forested hillsides. Selective cutting to a diameter limit of about 12 inches repeated every 10 years should result in the maintenance of a desirable forest cover. All logging should be done with animals. The denuded and badly eroding lands should be revegetated as soon as possible, using every means that will insure the quick establishment of a protection cover in the shortest possible

time. As the land is potential forest land, a new forest should be established.

Better agricultural practices and cooperation in the prevention of woods burning could be had through the offices of the county agricultural agents working together with the State extension forester and the State department of forestry. Research will also be necessary in the study of the erosion problem in relation to soil cover and in the determination of the best methods of reestablishing a forest cover on badly eroded areas.

The Homochitto drainage basin resembles very closely the adjoining basins to the north and south. Conditions there are also critical with respect to erosion and forest cover. Recommendations will therefore be taken up again in more detail in connection with the principal critical areas of the lower Mississippi River basin as a whole.

LOWER MISSISSIPPI (DIRECT)

(Area 40)

LOCATION AND AREA

The several areas considered in this section drain directly into the lower Mississippi River, cover 27,561 square miles of territory, and lie along both sides of the Mississippi River from southeast Missouri to central Louisiana. One of the largest of these areas is found in southeast Missouri and northeast Arkansas. The greater part of this area is drained by the St. Francis River, which empties into the Arkansas River in east central Arkansas. The Little River drains a small region in the northeast corner of this same area, adjacent to the Mississippi River. To the west lies the White River drainage basin. The highest elevation in the entire lower Mississippi drainage is found in the extreme northwest corner of this area, where an altitude of over 1,000 feet is reached.

In western Tennessee and Kentucky and extending for a short distance into northern Mississippi another area of the direct Mississippi River drainage is found. The Tennessee River basin forms its eastern boundary; the Yazoo highland watershed and the Mississippi River form the south and west boundaries, respectively. A part of the Ohio River drainage adjoins it on the north.

Just west of, and adjacent to, the Mississippi River and south of the Arkansas River drainage lies the Tensas River Basin. This has a long, narrow watershed bounded on the west by the Ouachita River Basin and on the south and southwest by the Red River drainage. The Atchafalaya, which does not drain directly ito the Mississippi but flows southward into the Gulf of Mexico, is not here considered as part of the lower Mississippi River drainage.

Two small areas remain to be considered: One, a small triangular area in southwestern Mississippi, lies between the Mississippi River and the watersheds of the Homochitto River and the Bayou Tallahala; the other extends south from the Homochitto drainage into southeastern Louisiana. The Mississippi River forms the western boundary of the latter, and the drainage basin of the Amite River forms the eastern and southern boundaries.

TOPOGRAPHY

The Tensas Basin is part of the flat alluvial lands of the Mississippi bottoms. About two-thirds of the watershed lies below an elevation of 100 feet. Drainage is poor throughout the greater part of the basin; the streams flow sluggishly and tend to meander.

North of the Tensas Basin, the St. Francis and Little River watersheds present similar topographic features, except that in the northern third of these drainage areas the flat, alluvial bottomlands give way to the rolling and hilly country of the northern Ozarks. Both the St. Francis and Little River rise in the hills of the northwest corner of this part of the watershed. Along the boundary between this drainage and that of the White River to the west, and mostly south of the Missouri-Arkansas State line, there is a long, narrow belt of rolling country known as Crowleys Ridge. This ridge slopes gently on both sides and merges into bottoms, or second bottoms. Its average height is less than 150 feet above the bottoms; the higher part is about 250 feet above the surrounding country. Most of this area is suited to farming.

East of the Mississippi River, the Kentucky, Tennessee, and Mississippi portions of the direct Mississippi River drainage present different topographic conditions. The flat land is limited to narrow belts of bottomland along the larger tributaries and to the extension of the Upper Coastal Plain soil region in northern Mississippi and southern Tennessee.

Although a broad belt of hilly country extends through the southeastern part of this drainage area in Tennessee, by far the greater portion of the drainage is rolling in nature. The elevations here range from 200 to 500 feet above sea level, the highest points being located in southern Tennessee and northern Mississippi.

These smaller tributaries lying to the east, although they do not flow swiftly, are less sluggish than those in the drainages west of the Mississippi River; they often carry heavy loads of silt which has been washed from the loess soils of the uplands. There is very little if any rock in the stream beds.

Those portions of the direct Mississippi River drainage which occur in southwestern Mississippi and southeastern Louisiana resemble closely the basins of the Bayou Tallahala and Homochitto Rivers. The small triangular area lying between these two latter watersheds is drained largely by Coles Creek. Excepting a narrow strip of flat, alluvial bottomland along the Mississippi River, the entire area lies within the rugged, severely eroded hills of the Mississippi Bluffs, which reach an elevation of 300 feet in this district. Here the streams have silty beds; they flow with moderate speed, but slow down and tend to meander where they reach the flood plain of the Mississippi River.

The small area south of the Homochitto River Basin in Mississippi and eastern Louisiana is similar to the districts farther north; the well-known Tunica Hills of Louisiana comprises a considerable part of this region. Taken as a whole, 52 per cent of the direct Mississippi River drainage is in flat, alluvial land; 30 per cent is rolling; and the remaining 18 per cent is hilly country.

GEOLOGY AND SOILS

The geological formation and soils of those portions of the direct Lower Mississippi drainage lying to the east of the river are essentially the same. Practically all of these scattered areas come within the Mississippi Bluffs and Silt Loam Uplands soil region.

The Mississippi Bluffs and Silt Loam Uplands are characterized by a soil of brown, silty material known as loess. It is generally believed to be of wind-blown origin and probably at one time extended much farther to the west than it does at present. The formation known as Crowleys Ridge, which lies west of the Mississippi River in Arkansas and Missouri, is composed of the same type of soil, and it is conceivable that these two areas formerly were continuous. It is believed that the present conditions came about through the erosive action of the Mississippi River in cutting its channel toward the east. The general supposition is that the soil forming the loess deposits came originally from sand bars or sand banks in the Mississippi River bottoms, and was transported inland during dry seasons by the prevailing southwesterly winds. Even to-day, during dry weather, clouds of dust bearing similar fine particles of soil can at times be seen drifting over the country to the east of the Mississippi River.

The heaviest and deepest deposits of loess material occur at the western border of the region, where they are often found to be 40 to 50 feet deep. In some places vertical bluffs of the same material rise 200 feet above the alluvial bottoms. The loess deposits become shallower to the east, and give way finally to the sandier, sedimentary soils of the Coastal Plain.

The loess soils show no evidence of stratification, but they are underlain by Coastal Plain soils which clearly show that their origin came through action of water. The line of division between the two deposits is sharp and distinct, very little intermingling of the two soils is apparent.

The characteristic, vertical erosion of the loess lands is due to the fineness of the soil particles and to a system of vertical lines of weakness. Weathering of this soil results in the formation of the typically perpendicular bluffs found most commonly along the western face of the region. Erosion, severe throughout this entire bluff country, forms characteristic vertical-sided gullies.

A relatively small percentage of these eastern portions of the drainage area is composed of the alluvial deposits of the Mississippi River and its tributaries. The limited extent of upper coastal plain soils found in southern Tennessee and northern Mississippi is made up of sedimentary deposits laid down in former times when this region was covered with water. Clays and sandy loams predominate. Erosion is not a serious factor in these areas of comparatively level topography.

West of the Mississippi River the largest part of the area is composed of the alluvial deposits of the Mississippi bottoms. Clays and clay loams predominate; but, although the physical structure of these soils is such that they are susceptible to erosion, the complete lack of topographic relief removes this danger.

In southeastern Missouri the rough hilly country is made up of igneous rocks and cherty limestone ridges which weather slowly.

In areas where the soft sandstone and purer limestone formations occur, weathering has proceeded more rapidly and the country is rolling in character. The general direction of the topographic relief is northwest and southeast. Stony and gravelly loams occupy much of the rougher country; these types of soil are subject to erosion where slopes are exposed. Erosion on the hill lands, however, because of the forest cover, is not serious at present. The most serious erosion takes place on the silt loams of the lower rolling areas where considerable land has been cleared. Both gullying and sheet erosion occur; the former is the more noticeable on steeper slopes. Although gullying is the more noticeable, sheet erosion is far more destructive to the fertility of Missouri soils.

CLIMATE

The mean annual precipitation in the areas drained by small streams flowing directly into the Mississippi is about 45 inches in Missouri and Kentucky, 47 inches in Tennessee and Arkansas, and 58 inches in southern Louisiana. About half of this falls during the warm season in the vicinity of western Tennessee, and slightly more than half in Louisiana. About 14 inches ordinarily falls throughout these areas during the three months' period of March, April, and May, but in 1927 21 inches fell during March and April. In general, the precipitation is medium for the northern parts of the drainage area and heavy in Louisiana.

For the northern portion the mean temperature for the year is 58° F.; for January, 35 to 40°; and for July, 80°. The ground is covered with snow for an average of 10 days each year. For the southern (Louisiana) portion the mean temperature is 69° for the year, 50° for January, and above 80° for July. Here snow is absent, or covers the ground for less than a day each year.

HISTORICAL DEVELOPMENT

Great variety in land use exists in the drainages of the smaller streams and rivers emptying directly into the Mississippi. For instance, in the Obion River drainage in Kentucky and Tennessee the proportion of land under cultivation approaches the maximum for any part of the lower Mississippi Basin, while the soil, topography, and general condition of cover combine to make the area critical from the standpoint of soil erosion. In contrast are the bottoms of the Tensas drainage, with almost the lowest proportion of cultivated land in the lower Mississippi Basin, and with danger of erosion reduced to a minimum by the flat topography. The history of settlement, methods of agriculture, character of ownership, and extent of artificial drainage are discussed in detail below for the various parts of these disconnected areas.

CONDITION OF LANDS OTHER THAN FOREST AND CONDITION OF FORESTS

For convenience the items under both these headings will be discussed together for each of the smaller drainages.

(*a*) *Little River, Mo.*—The Little River drainage lies in eastern Missouri between the Mississippi on the east and the St. Francis

drainage on the west. Its area is 2,834 square miles, about 67 per cent of which is in farms. Twenty-seven per cent (775 square miles) of this minor drainage lies within the boundaries of the upland hardwood type, which here contains 20 per cent or more of short-leaf pine. Within this type 42 per cent of the area (325 square miles) is in woodland and forest, of oaks, hickories, and other upland hardwoods, and of pine, only occasionally burned over, and with a rating of 85. Twenty-five per cent (194 square miles) is unimproved, and is rated at 65. The remaining 33 per cent is cultivated, producing corn and similar crops under contour plowing; it is rated at 70. The total cover rating for the area within the type boundaries is 75.

Seventy-three per cent (2,059 square miles) of this entire district falls within the bottomland hardwoods type, the forested parts of which include red and tupelo gums, some cypress, and sycamore, bottomland oaks, and various other hardwoods. The forested portion covers 32 per cent of the area, or 659 square miles; it is rated at 95. Unimproved land, with a rating of 75, covers 17 per cent (350 square miles). Cultivated land, principally in corn and cotton, covers 51 per cent of the area; it has a rating of 90. The total cover rating of the type is 89.

Much of the Little River drainage is swampy. Fires are not serious, except during years of considerable drought. Cover conditions as a whole are fairly good, but the drainage has relatively little influence on the Mississippi floods.

(*b*) *St. Francis River.*—The St. Francis River rises in the Missouri Ozarks, and winding south between the drainages of the Black and the lower White Rivers on the west and the Little and Mississippi Rivers on the east runs into the last-named stream a short distance above the mouth of the Arkansas River.

The drainage of the St. Francis covers 7,058 square miles, of which 45 per cent is in farms and most of the rest in the hands of lumber companies.

Of the total area, 15 per cent of 1,059 square miles falls within the boundaries of the upland hardwood type, largely in the easternmost extension of the northern Ozarks. Here, as in the Little River drainage, the type contains 20 per cent or more of short-leaf pine. Oaks and hickories are the predominating hardwood species. Woods burning is not uncommon, and the woodland and forest, which covers 42 per cent (445 square miles) of the area within the boundary of the type, is rated at 85. Unimproved land, 41 per cent (434 square miles), part of which is in grass or brush, and some of which is subject to burning, is rated at 65; and improved lands, 17 per cent (180 square miles), also rated 65, are largely in corn. The total cover rating for the type is 73.

Eighty-five per cent (5,999 square miles) of the total area lies within the boundaries of the bottom-land hardwoods type; red and tupelo gum, cypress, and oaks are the predominating species. Approximately 42 per cent (2,519 square miles) of the area within the type is forested and has a rating of 95. Cutover and other unimproved land, much of it brushy and little or none of it severely burned, covers 25 per cent (1,500 square miles), and is rated at 75; improved land, 33 per cent (1,980 square miles), largely in corn, is rated at 90. The cover rating for the type is 88.

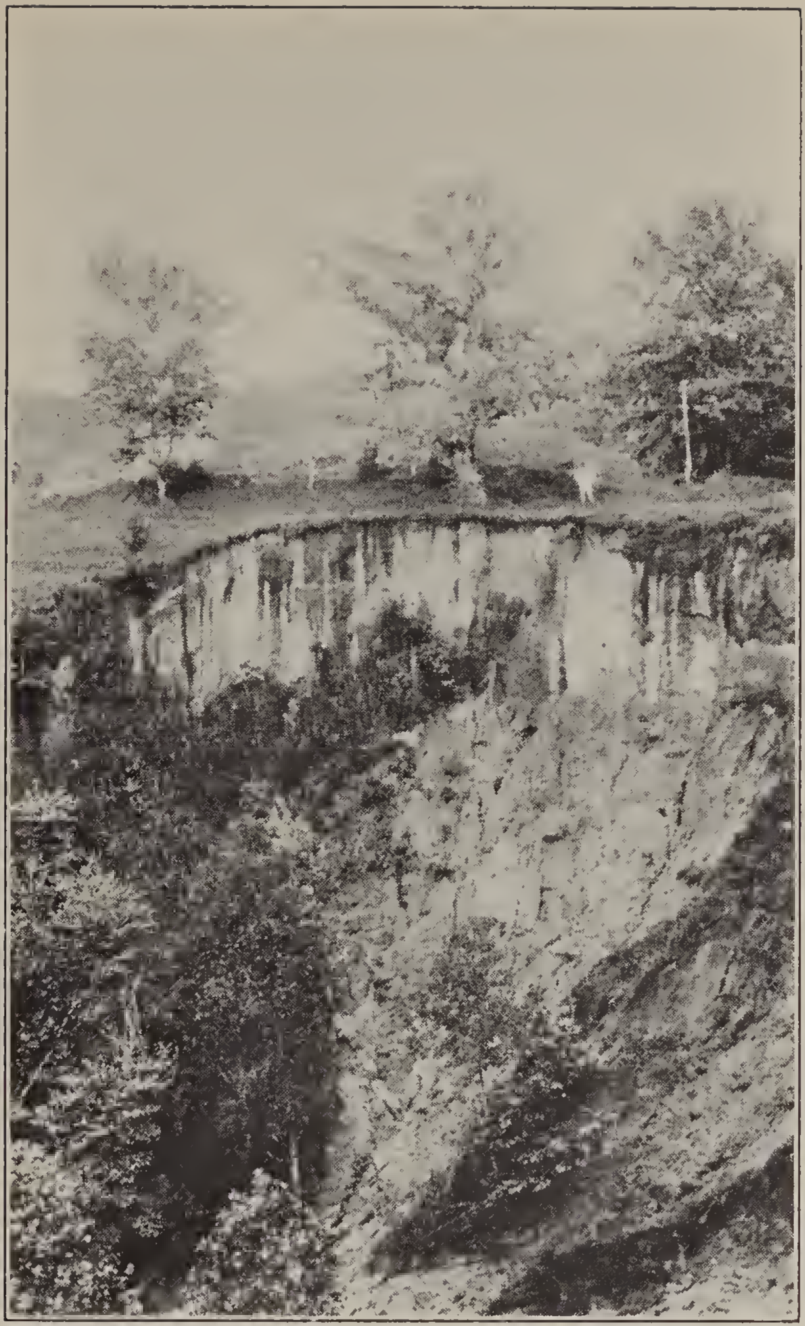

FIGURE 11.—Examples of erosion of loess soil in Wilkinson County, Miss., 4 miles east of Fort Adams, a town on the Mississippi River. This land was in cotton cultivation in 1890. Timber growth would have prevented this soil wash. Mississippi Direct. (Two views)

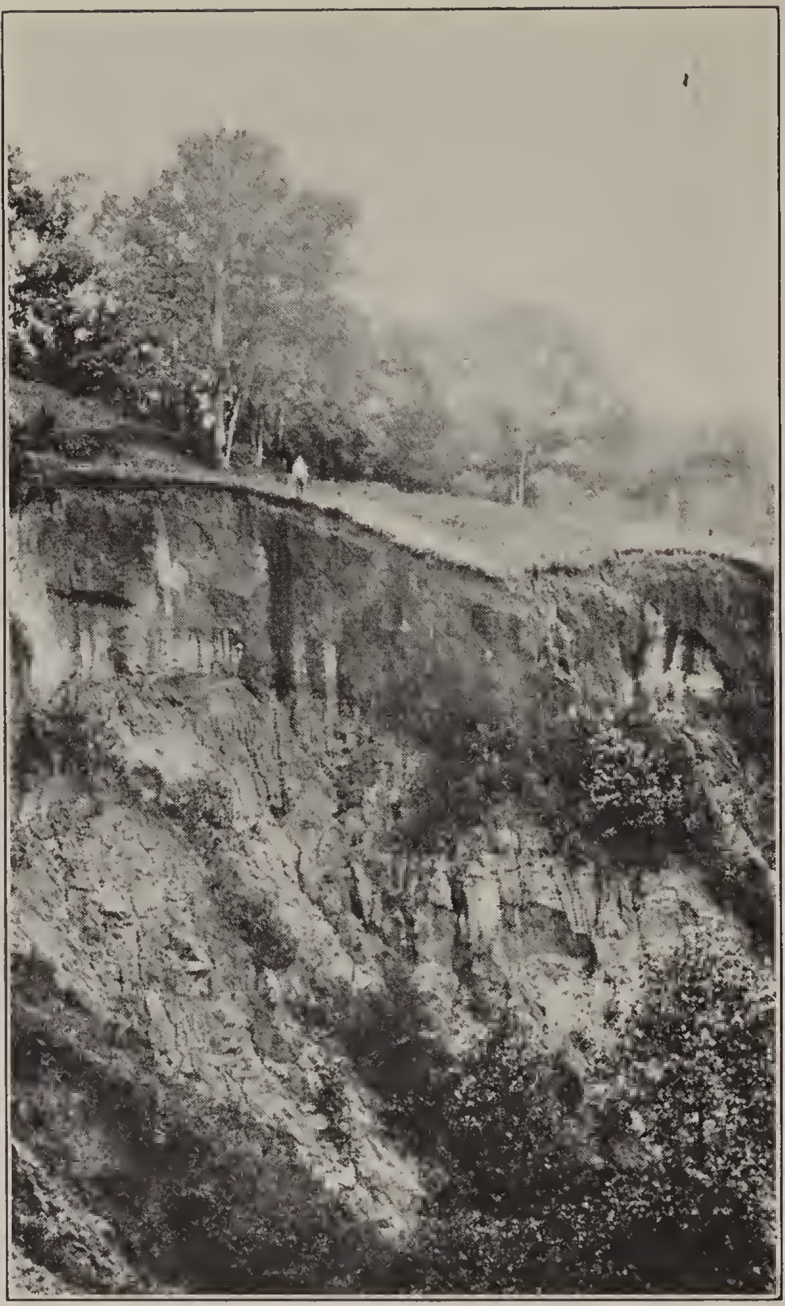

FIGURE 12.—Examples of erosion of loess soil in Wilkinson County, Miss., 4 miles east of Fort Adams, a town on the Mississippi River. This land was in cotton cultivation in 1890. Timber growth would have prevented this soil wash. Mississippi Direct. (Two views)

FIGURE 13.—Soil erosion caused by removal of forest cover. Land gullied near Oakland, Fayette County, Tenn.

FIGURE 14.—Hilly farm land—once corn land—now pasture for cattle. Gulleys are 10 to 15 feet deep. Here exists a great need of forestation. Two miles south of Gleason, Weakley County, Tenn.

The St. Francis contributes a considerable amount of water to the Mississippi, together with some silt washed down from the hills at its source and from local erosion areas on the east side of Crowley's Ridge. The discharge of the water is delayed, however, by the flooding of the bottom lands and swamps in the lower stretches of the drainage, and, when it is flooded by waters breaking through from the Mississippi, this drainage might be considered a natural reservoir. Topography rather than cover, however, makes the storage function possible.

(*c*) *Obion River.*—The Obion River drainage lies in the northern half of extreme western Tennessee and extends a short distance into the southwest corner of Kentucky. It is a highly developed agricultural region. The total area is 4,700 square miles, 12 per cent (566 square miles) of which lies within the boundary of the bottom-land hardwoods type, and 88 per cent (4,134 square miles) within that of the upland hardwoods type.

The bottom-land hardwoods type fringes the western border of the drainage and extends up the larger streams. Twenty-seven per cent (153 square miles) which rates 100, is in woodlands and forest of gums and oaks; 27 per cent (153 square miles), rating 80, is in unimproved land; and 46 per cent (260 square miles), rated at 90, is in cultivated land devoted principally to corn and cotton. The total cover rating for this part of the drainage is 90, but the location and limited extent of the area preclude its having any great effect on run-off and erosion.

Of the area within the upland hardwood type, 30 per cent (1,240 square miles) is in oak-hickory forest, seven-tenths of which is in the form of wood lots. Fires are frequent and grazing is common. Woods are often cut clear. On most of the wooded area litter is less than an inch deep, although in places it attains a depth of 3 inches. The rating of the wooded portion is 85; that of the 30 per cent (1,240 square miles) of unimproved land is only 60; and that of the 40 per cent (1,654 square miles) of cultivated land, largely in corn and similar crops, with contour plowing, but little or no terracing, is only 70. The total cover rating for the land within the type boundary is 71. This area is critical and exerts a detrimental influence on run-off and erosion.

(*d*) *Hatchie River.*—The Hatchie River rises in northern Mississippi and flows north and west through the southern and central part of extreme western Tennessee to the Mississippi River. The region is primarily agricultural, 71 per cent of the land being in farms. Approximately 9 per cent (256 square miles) of the area lies within the boundaries of the bottom-land hardwood type, along the Mississippi and the lower Hatchie and its tributaries. The remainder of the area lies within the upland hardwoods type.

Within the bottom-land hardwoods type 29 per cent (74 square miles) of the area is in forest composed largely of gums and oaks, rated at 100; 29 per cent (74 square miles) is in unimproved land, rated at 80; and 42 per cent (108 square miles), rated at 90, is in cultivation. The average cover rating for the type is 90, but the area is so located that it has little effect on floods.

Of the area within the boundaries of the upland hardwoods type 40 per cent (987 square miles) is in woodland and forest of oaks and hickories, which are occasionally burned; it has a rating of 85; 31

per cent (765 square miles) is in unimproved land and has a rating of 60; and 29 per cent (715 square miles) is in cultivated land rated at 70. The average cover rating for the type is 73, which indicates a detrimental influence on this critical area.

(*e*) *Wolf River.*—The Wolf River rises in northern Mississippi and flows north and west through southwestern Tennessee to the Mississippi River. Its drainage lies between that of the Hatchie on the north and east and the Yazoo Highlands on the south. The total area is 1,888 square miles, of which 23 per cent (432 square miles) is within the boundaries of the bottom-land hardwoods type and 77 per cent (1,456 square miles) is in the upland hardwoods type. Agriculture is the chief industry and 70 per cent of the area is in farms.

Within the boundaries of the bottom-land hardwoods type, 36 per cent (156 square miles) of the area, with a rating of 100, is in forest consisting of gums, oaks, and some cypress. An additional 36 per cent (155 square miles), rated at 80, is in unimproved land, and 28 per cent (121 square miles), with a rating of 90, is in cultivation. The total cover rating for the type is 90, but the location makes this cover of little effect in flood control.

Twenty-eight per cent (408 square miles) of the more extensive area within the boundaries of the upland hardwoods type is in forest consisting mainly of oak and hickory with a little shortleaf pine in mixture. Some fires occur here. The rating is 85. The 33 per cent (480 square miles) of unimproved land, much of it abandoned farm land, rates 60, and the 39 per cent (568 square miles) of cultivated land rates 70. The average rating for all cover in this type is 71, indicating a detrimental influence for this critical area.

(*f*) *Tensas River.*—The Tensas River rises in northeastern Louisiana and flows south through northeastern Louisiana. The Bayou Macon, the main tributary of the Tensas, rises in southeastern Arkansas, near the mouth of the Arkansas River. The Ouachita joins the Tensas a short distance above the Red River; the two form the Black River which enters the Red just above its mouth. The Tensas might more properly be included in the Red River drainage, but for the purposes of this study, it has been assigned to the lower Mississippi direct. The Tensas drainage, which has an area of 4,180 square miles, is level, subject to overflow, and, on the whole, well forested, and contributes little to the load of silt in the Mississippi. The Tensas receives a portion of the flood waters from the Arkansas and from the Mississippi itself, thus acting as a safety valve and storage reservoir for the latter stream.

Practically all of the Tensas drainage falls within the boundaries of the bottom land hardwood type, consisting of red gum, various oaks, pecan, and ash, with small amounts of cypress and tupelo gum. Only 34 per cent of the land is in farm ownership, most of the rest belongs to large lumber companies. Of the total area, 41 per cent (1,714 square miles), rated at 100, is in forest; 43 per cent (1,797 square miles), rated at 85, is in unimproved land; and 16 per cent (669 square miles), rated at 95, is in cultivated land. The total cover rating for the entire type and basin is 93.

(*g*) *Atchafalaya River.*—Because its drainage is indeterminate, and because it empties into the Gulf of Mexico instead of into the Mississippi, the Atchafalaya River has been omitted from this study.

(*h*) *Miscellaneous smaller tributaries draining directly into the Mississippi.*—Included in the lower Mississippi direct, but not mentioned in the discussion above, are five small areas; (1) in eastern Missouri above the Little River drainage; (2) in southwestern Kentucky and northwestern Tennessee; (3) between the Bayou Tallahala and Homochitto River drainages in southern Mississippi; (4) between the Homochitto drainage and the Missippi-Louisiana line; and (5) lying east of the Mississippi River in Louisiana. The largest (2) has an area of 1,414 square miles and the two smallest, (3) and (4), contain about 525 square miles each. All contain critical or near-critical areas; all except (5) lie more in pine or upland hardwood types than in bottom land hardwoods, and exhibit a detrimental influence in respect to floods. Their size, location, and relatively small drainage basins, however, make them of much less importance than the adjacent drainages discussed in detail in this and other minor drainage reports; and it seems sufficient to dismiss them with a reference to these adjacent drainages for general description. Their areas, by types and conditions, together with the ratings assigned them, are given in the appropriate tables in the major tributary report for the Lower Mississippi Basin.

To sum up, the lower Mississippi direct drainage, with a gross area of 27,561 square miles (excluding the basin of the Atchafalaya, which does not empty into the Mississippi), has 4 per cent of its area, 1,008 square miles, within the boundaries of the pine type; 14,915 square miles, or 54 per cent, within the bottom land hardwoods types; and 11,638 square miles, or 42 per cent within the upland hardwoods type. Within this area as a whole all the critical areas except Crowley's Ridge and the eastern Missouri hills lie to the east of the Mississippi. Most of the land on the west side is of relatively small importance in flood control, though much of it suffers directly from floods originating elsewhere.

The upland hardwood type, lying as it does on the higher lands which constitute the critical areas, is of most importance from the standpoint of flood control and erosion. It includes 34 per cent (3,900 square miles) of woodland and forest, much of it burned at intervals. but with an average rating of 85; 29 per cent (3,424 square miles) of unimproved land, much of which is washed and gullied almost beyond reclamation, with an average rating of 61; and 37 per cent (4,314 square miles) of cultivated land, as a whole insufficiently protected against erosion, and rated at 70. The total cover rating for the type is 72. Next in importance is the pine type, which occurs on three critical areas—two in Mississippi and one in Louisiana. Fire is more common on the 35 per cent (348 square miles) of woods and forests than in the corresponding cover in the upland hardwood forests, and the pine forests are rated at 82; unimproved land occupies 50 per cent (504 square miles) of the area, and is rated at 64; and cultivated land, rated at 74, occupies 15 per cent of the area, or 156 square miles. The total rating for the type is 71.

Because of its location the bottom land hardwood type, with a total cover rating of 90, is of practically no importance in the study of run-off and erosion.

CRITICAL AREAS

Within this series of direct drainages the following areas appear critical from the standpoint of flood control:

(1) The region in southeastern Missouri belonging to the northern Ozark soil province where, mainly because of the hilly topography, soil erosion must be guarded against.

(2) Crowleys Ridge in southeastern Missouri and northeastern Arkansas, which is similar, as regards soil formation, to the Mississippi bluff lands on the opposite side of the Mississippi River. Here soil erosion is serious mainly on cultivated land, and this can be overcome by improved agricultural practices and by keeping the steepest slopes in forest cover. Such forest cover can be maintained by fire protection and conservative cutting practices.

(3) Practically all of the lands which occur in the Mississippi bluffs and silt loam uplands soil province lie east of the Mississippi River and adjoin similar areas to the north and south. Together these areas in several different drainages from a belt stretching from the western tip of Kentucky to eastern Louisiana, bounded on the west by the flood plains of the Mississippi River and on the east by an irregular line which marks the eastern termination of the rough, easily eroded hill country of the silt loam uplands where they merge with the more level coastal plain soils. It is here that soil erosion is at its worst, with practically no steps being taken to improve conditions. Typical of this region is the Yazoo highlands, concerning which Dr. E. N. Lowe, the State geologist of Mississippi, has made the following statement:[1]

> The interrelation of deforestation of the uplands, rapid erosion of the soils, extensive stream filling, and destructive flooding of lowlands, seems evident in the Yazoo drainage basin. It seems equally evident that these distressing conditions are yearly growing worse instead of better, calling for immediate and effective remedial treatment. But no remedy will be effective which does not strike at the root of the evil. The rapid erosion of the uplands must be stopped. In the more broken areas forests or other protective growth will be necessary, and in the less broken parts seeding the soil with Bermuda grass and other forage plants may be used effectively. Where great chasms have developed and are yearly cutting deeper into the hillslopes, damming would be too expensive to attempt in this stage of agricultural development. But an effective remedy consists of seeding the bottoms of these washes in black locust and honeysuckle. In a few years these begin to mat the washing surface so thickly as to stop the washing and promote filling. Usually at this stage these may be reinforced in the open spaces with Bermuda grass.
>
> These methods are proving satisfactory in many places and within a few years will produce notable results.

The rating given to these scattered drainages has been put at 76.

RECOMMENDATIONS

Most of the critical areas occurring in these widely scattered minor drainages of the lower Mississippi River can best be handled in conjunction with the adjoining areas which have been discussed in detail under recommendations for the Bayou Tallahala, Yazoo Highlands, Homochitto, and Big Black River Basins in Mississippi. The solution of the soil-conservation problem in this region hinges on Gov-

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[1] Lowe, Dr. E. N. Lumber World Review. Feb. 25, 1922.

ernment control because little or nothing is being done by—or can be anticipated from—the districts affected. The establishment of either National or State forests, or both, would assure the quickest and most effective remedy at the present time, especially in the area lying within the boundaries of the States of Mississippi, Louisiana, and Missouri. Probably State action alone would be sufficient in Kentucky and Tennessee; but in all of the districts included in these drainages past damage can be repaired and future mistakes avoided only through maintaining or replacing a forest cover on such slopes as are subject to excessive erosion and in limiting cultivation to the more level areas. The forest land must be protected from fire and the cutting practices regulated so that the forest cover is never entirely removed; barren or severely eroded places must be replanted to trees. The introduction of improved agricultural practice such as contour plowing and terracing is essential and will necessitate the closest cooperation between county agricultural agents, extension foresters, and State departments of forestry.

The critical area in southeastern Missouri should be included in any plans leading toward improvement of conditions in the Ozark region as a whole, most of which lies in adjoining drainages. The Crowley's ridge region is too valuable as agricultural land to be kept in forests (excepting the steeper slopes); and improved agricultural practices will be sufficient to prevent further erosion in this region.

Detailed investigations of each of the regions considered critical will be necessary before estimates of the area of forest land needed for protection purposes can be made. Development of methods of erosion prevention and study of the measures needed to stop erosion which has already started will be necessary also and should be undertaken immediately by the agencies best equipped to handle such investigations.

YAZOO BOTTOM LANDS

(Area 41)

LOCATION AND AREA

The Yazoo bottom lands, covering a gross area of 7,324 square miles, are located in northwestern Mississippi. The boundary of this region extends from the Mississippi River near the Tennessee line southwards nearly to Vicksburg. The Mississippi River forms the entire western boundary of these bottom lands. The rugged line of the Mississippi Bluffs on the east divides the bottom lands from the Yazoo Highlands, and to the southeast lies the Big Black watershed.

TOPOGRAPHY

This drainage basin is about 180 miles long and 60 miles wide at its widest part, tapering gradually to a point at both northern and southern extremities.

Ninety-two per cent of this entire region, known as the Yazoo Delta, consists of a flat, alluvial plain which slopes gently southward. Portions of the Mississippi Bluff lands occur in the southeast corner of this watershed, composing the remaining 8 per cent of the area.

At the Tennessee line near the northern tip of the bottom lands, the elevation is 217 feet above sea level. Vicksburg, near the southern extremity, has an elevation of 97 feet. Due to this lack of topographic relief, drainage is poor and the streams are sluggish and inclined to meander. Long, narrow, crooked lakes and bayous formed by the abandonment of old stream channels, are of common occurrence.

Clays form the predominating soil type and occupy the lower, more poorly drained lands, farther from the streams. The silt deposits from the periodic overflow of the streams have formed ridges, the highest portions of which are always found nearest the water courses because of the immediate deposition of the heavier soil particles whenever the stream overflows its banks. As the velocity of the overflow decreases with increased distance from the main stream bed, due to the obstruction of vegetation, the carrying power of the water also decreases, causing further deposition of sediment.

Although this whole area was originally heavily timbered, most of it is now in a high state of cultivation, the land having been rapidly converted into farms after the timber had been cut off.

GEOLOGY AND SOILS

The soils of the Yazoo bottom lands are almost entirely made up of alluvial deposits, the single exception occurring in the comparatively small area of wind-blown, or loess, soil of the Mississippi bluff region in the southeast corner of the watershed.

Along the eastern border of the bottom lands adjacent to the Mississippi Bluffs there is a soil type composed of material which has been washed down from the hill land of the upper Yazoo. This area is but a few miles wide at most and, being somewhat higher than the adjacent bottom lands, is well drained, and makes up an extremely fertile agricultural region. Stiff, impervious clays predominate over the remaining portion of the bottoms. Narrow belts of loam occur along the streams.

The composition of these soils is such as to make them very susceptible to erosion, but the complete lack of topographic relief removes this danger. Erosion in the Yazoo bottom lands is limited entirely to the small area of loess soils in the southeast corner. Here, as in adjacent watersheds containing loess deposits, gullying of unprotected and uncared-for lands is proceeding rapidly.

CLIMATE

The mean annual precipitation is 50 inches, half of which falls during the warm season. About 15 inches of rain normally falls during March, April, and May, but in 1927 the rainfall amounted to 21 inches during March and April. As compared with other areas in the lower Mississippi region the normal precipitation is medium in amount.

The mean temperature is about 64° F. for the year, 40° to 45° for January, and 80° for July. Snow covers the ground for two or three days per year.

HISTORICAL DEVELOPMENT

Parts of the Yazoo bottom lands were settled and farmed as early as 1763, and agricultural development has continued more or less steadily since then. Agriculture and lumbering are the most important activities of the region.

The first agricultural settlements took place on the higher lands fronting on main streams, and, to-day, cultivated areas are limited largely to these frontage lands. Wherever farms have been abandoned, as occasionally they have been, outside the levees, forest growth has come back with a heavy undergrowth of grass and vines. Logging of both cypress and hardwoods became increasingly important after 1900, and it still continues to be an important industry, although the stands of virgin cypress are now nearly exhausted.

Ninety-five per cent of this watershed lies within the natural boundaries of the bottom land hardwoods type, which extends up the streams into the bluff lands; 5 per cent lies within the upland hardwoods type on the bluffs themselves. Of the total area of 7,324 square miles, 48 per cent, or 3,548 square miles, is in forest, 15 per cent, or 1,099 square miles, is in unimproved lands, and 37 per cent, or 2,677 square miles, is in cultivated land. Slightly less than 54 per cent of the total area is in farms; only 22 per cent of the forested area is in farm wood lots; the rest is largely in the hands of lumber companies. The Yazoo bottom lands, excepting the 5 per cent of the total which lies within the upland hardwood type, contribute practically nothing to the load of silt carried by the Mississippi; indeed, they suffer considerably from deposits of silt washed down from the Yazoo Highlands. The lowlands, embracing swamps, overflow lands, and the tortuous channels of the streams, act as a storage basin, and partially prevent excessive discharge of flood waters into the Mississippi. They, too, suffer from destructive floods which originate in the Mississippi proper as well as in the upper Yazoo. The cover rating of this part of the drainage is 90, but the beneficial effect is far less than that resulting from a similar cover on steeper ground or nearer headquarters of minor drainages or main streams.

CONDITION OF LANDS OTHER THAN FOREST

Cotton is the principal crop in the Yazoo bottom lands; corn is next in importance. Contour plowing is practiced on the sloping fields, and cultivation as a whole does not contribute seriously to the erosion of the region. Improved land, for the drainage as a whole, is rated at 89.

Unimproved land, largely because of occasional fires, is rated somewhat lower, at 78. Burning is a less serious factor here than in the upland types, and here there is a greater tendency for brush and heavy grass to invade land not in forest or cultivation.

CONDITION OF FORESTS

All but 1 or 2 per cent of the forest is in the bottom land hardwoods type. This type is composed of red and tupelo gums in the wet places and of oaks and a great variety of other hardwoods in the better-drained sites. Formerly there were magnificant stands of

cypress which have now been largely cut out and replaced by gum. Much of the land classed as forest has been logged over but still supports enough trees, either from the original stand or from second growth, to maintain an effective forest cover. Fires are comparatively rare and grazing has no appreciable effect on the forest. A small portion of the area is included in drainage projects of one sort or another, but no information is available concerning damage done to the forest by the drainage. Litter and humus are heavy for the South, often attaining a depth of 2 inches and occasionally much more. Sphagnum areas of unknown extent occur. The rating for the bottom land hardwoods type is 95. The small amount of upland hardwoods, consisting of oaks, hickories, and numerous other hardwoods, and shortleaf and loblolly pine, is rated at 80. The forest rating for the Yazoo bottom lands as a whole is 94.

CRITICAL AREAS

The only part of this watershed where conditions are critical from the standpoint of soil erosion is a relatively small strip of bluff country adjacent to the Big Black River drainage basin on the southeast. Here topography, soil, and rainfall combine to cause a serious erosion problem. Because this adjoins a similar district in the Big Black River watershed, the discussion under that region will apply here. In as much as but 5 per cent of the entire Yazoo bottom land is included in this critical area it has little effect on the protective rating of the watershed, which is 82, the highest of any in the lower Mississippi River drainage.

RECOMMENDATIONS

The area which ought to be retained as a protection forest is limited to the bluff region. A much more extensive area with similar conditions prevailing is found in the adjoining Big Black River drainage basin, and any soil or forest conservation measures which might be instituted there would apply as well to this portion of the Yazoo drainage, which makes up but 5 per cent of the entire area. The remaining 95 per cent, which has no effect on the flood problem, will continue for the present to be more valuable for agricultural purposes than for any forest development.

YAZOO HIGHLANDS

(Area 42)

LOCATION AND AREA

The Yazoo highlands, occupying 6,496 square miles, lie in the north central part of the State of Mississippi, east and northeast of the Yazoo bottom land country. The north Mississippi portion of the direct Mississippi River drainage forms the northern boundary. A part of the eastern boundary is formed by the divide between the Tombigbee and upper Yazoo River drainage areas. To the southeast lies the upper portion of the Big Black River drainage.

TOPOGRAPHY

Practically the entire watershed is a well drained, rolling to hilly country, approximately 59 per cent being classed as hilly and 36 per cent rolling. The remaining 5 per cent of the area situated in the northeast corner of the watershed is relatively flat. The general elevation ranges between 300 and 600 feet above sea level, with the greatest altitude near the Tennessee line. A few points in Marshall County on the northern border of the State reach an elevation of 700 feet.

The Mississippi Bluff region forms a belt from 5 to 15 miles wide extending along the western border of this basin and reaching into Tennessee and Kentucky on the north, and into Louisiana on the south. The greater part of these bluff lands consists of steep, severely eroded hills, although in northern Mississippi and in Tennessee they may be classified as rolling land more properly than as hills. Regardless of the topographic relief, this entire strip of country is subject to erosion of a very severe and destructive nature.

East of the bluffs lies a broad, rolling, or hilly area known as the silt loam uplands. The hill country proper occurs in the western part of the highlands adjacent to the bluffs and extends from the northeastern part of Madison County, northward through Leake, Attala, Montgomery, Grenada, Calhoun, Yalobusha, Lafayette, and Marshall Counties, into Tennessee. South of Marshall County the hilly country is limited almost entirely to the bluff lands. East of the hills the country is rolling, and gradually slopes off into a relatively flat country in eastern Mississippi.

The bottom and terrace lands along the larger streams range from 1 to 3 miles in width. Streams as a rule are fairly swift, and during seasons of high water they carry a heavy load of silt, which is later deposited on the flat lands of the lower Yazoo. Stream beds contain little, if any, rock, gravel being the coarsest material found.

GEOLOGY AND SOILS

The Mississippi Bluffs, a strip of country only 5 to 15 miles wide, lying along the western border of the highlands of the Yazoo Basin, are characterized by a soil of brown silty material known as loess. This is generally believed to be of wind-blown origin and probably at one time extended much farther to the west than it does at present. The formation known as Crowley's Ridge, which lies west of the Mississippi River in Arkansas and Missouri, is composed of this same type of soil, and it is conceivable that these two areas were at one time continuous. The change came about gradually through the erosive action of the Mississippi River in cutting its channel toward the east. The general supposition is that the soil forming the loess deposits was carried by the wind from sand bars or sand banks in the Mississippi River bottoms. Even now during dry weather clouds of dust, consisting of similar fine particles of soil, can be seen at times drifting over the country to the east of the Mississippi River.

The heaviest and deepest deposits of loess material occur at the western border of the region, where they are often found to be 40 to 50 feet deep. They become shallower farther east, giving way

finally to the sandier sedimentary soils of the coastal plain. Practically all of the soils of this upper Yazoo watershed are classified as loams.

The loess soils show no evidence of stratification, but they are underlain by coastal-plain soils which plainly give evidence of their origin through action of water.

The characteristic vertical erosion of the loess country is due to the compactness of the soil material and its tendency to vertical lines of weakness. Weathering of this soil results in the formation of the typically perpendicular bluffs commonly found along the western border of the region. Erosion is severe throughout this part of the Yazoo watershed, characteristic vertical-sided gullies resulting.

CLIMATE

The mean annual precipitation is 50 inches, half of which falls during March, April, and May; but in 1927, 25 inches of rain fell during March and April. As compared with other areas in the region, the precipitation is medium in amount. Cultivated lands are subject to severe injury by the frequent torrential rains. Periods of drought occur only occasionally.

The mean annual temperature is about 62° F., and snow covers the ground only four or five days per year, on the average.

HISTORICAL DEVELOPMENT

The Yazoo highlands were first settled about 1835. The original cover was almost entirely forest. Clearings have been made principally for agriculture, which is still the leading occupation. The region contains a vast amount of worn-out, eroded, and abandoned land. Woodland and forest now occupy approximately 38 per cent of the area; unimproved, including abandoned land, 34 per cent; and cultivated land, 28 per cent. Some 78 per cent of the total area is in farm ownership.

The forested area (two-thirds of which is in farm wood lots) is well broken up. Woods burning is common and cutting is largely haphazard; as a result the forested area is in poor condition. Repeated burning, unchecked erosion, and abandonment of land after improper cultivation have left a considerable part of the unimproved land in even worse condition. No other area of similar extent in either the Lower Mississippi or the Red River drainage has been given as low a rating, 67 for the cover as a whole; nor can any other area show more critical local conditions.

CONDITION OF LANDS OTHER THAN FOREST

Probably less than 10 per cent of the improved lands within the Yazoo highland region occupy level areas, and these are situated principally near the beds of streams. These lands, largely in cotton and corn, suffer relatively little from erosion and are not a serious factor in rapid run-off.

Most of the cultivated lands lie on moderate or steep slopes where the soil is highly susceptible to washing. Contour plowing, of absolute necessity, is universally practiced, but only a small amount of

FIGURE 15.—A 36-inch overcup oak fire-scarred at base, with water mark at 8 feet above ground. Yazoo bottomlands. Sunflower River, Miss.

FIGURE 16.—Gully to be reclaimed as demonstration. Yazoo Highlands, 5 miles east of Sardis, Miss.

terracing is done and there is little or no systematic use of vegetative cover to prevent erosion. Cotton and corn, both intertilled, are the principal crops. Of late years, with the increase in tenant farming, few attempts have been made to control the erosion of plowed fields other than by contour plowing. The result has been an appalling abandonment of fields at a time when the cultivated area in the adjacent lowlands has actually been increasing. Cultivated lands in the condition just described are undoubtedly an important contributing factor in the Mississippi floods. The effect on the Yazoo bottom lands is especially severe. This is due not so much to the rapid run-off from the highland slopes as to the deposit of silt left as the floods recede. The rating given to cultivated land in the highland region is 66.

If improved lands exert a detrimental influence, most of the unimproved lands do so to an even greater degree, since they include many abandoned fields on which erosion is entirely uncontrolled. The region contains approximately 2,223 square miles of unimproved land, of which a considerable proportion has been dropped from cultivation since the census of 1920. Natural revegetation of such abandoned land is often difficult; and the longer the land goes without some cover the more extensive is the damage. Shortleaf pine seedlings and grass often invade old field areas and form a protective cover; blackjack oak brush helps to prevent erosion on some cut-over lands that never have been plowed; and good pasture of Bermuda and other grasses protects part of the land classified as unimproved. The total rating for unimproved land in this drainage, however, has been put at 56.

CONDITION OF FOREST

Six per cent (383 square miles) of the Yazoo highland area lies within the boundaries of the bottom-land hardwood type. About 44 per cent of this (169 square miles) is in woods and forest, consisting of red and tupelo gums, some cypress, various bottom-land oaks, and other hardwoods. These forested areas, scattered along the bottoms of the larger streams and fringing the extreme southwestern edge of the upland area are in the best condition of any of the lands included in the Yazoo highland boundaries; they are rated at 95, but because of their location they have practically no influence on erosion and run-off.

Of the 94 per cent (6,113 square miles) of the entire drainage area which falls within the boundaries of the upland hardwoods type, 37 per cent (2,262 square miles) is in woods and forest, about two-thirds of which is in farm wood lots. Here the upland hardwood type is made up of a mixture of upland oaks, hickories, and, especially toward the south, as much as 20 per cent each of shortleaf and loblolly pines. Shortleaf occurs more commonly in this region than does loblolly. Pure stands of pine are often found where shortleaf has come in on cleared land. Woods burning is fairly common and has resulted in the complete destruction of the scanty leaf litter characteristic of southern forests, with consequent erosion; occasional unburned wood lots show that even the half inch or so of accumulated vegetable material characteristic of this type is effective in preventing erosion where gullying has not already started. Vir-

gin forests in this type are usually clear cut, with serious erosion resulting. Heavy grazing, either in the forested areas or on the unimproved lands, results in but a moderate increase in erosion.

To sum up, the bottom-land hardwood forests, although in good condition, are relatively unimportant, while the vitally important and much more widely distributed upland hardwood forest (with a mixture of pine in places) has not only been reduced far more than it should have been but, because of destructive logging and especially woods burning, it fails to exert its maximum beneficial influence. The bottom-land hardwood forest has a rating of 93, the upland of 75.

CRITICAL AREAS

Practically the entire region known as the Yazoo Highlands is a critical area; its present cover conditions are detrimental in their influence on the Mississippi River flood problems. The small extent of bottom land along the western edge and parts of four or five counties in the eastern half of the watershed have not been included in this critical area because the land on those portions is nearly level. There, also, the soil seems to be more absorptive of moisture. The eastern section is part of the area often called the "Black Prairies." Over 25 per cent of this black-prairie district is now in hardwoods. With these exceptions the Yazoo Highlands present an extremely urgent problem. The average rating given to this area is 65, about the same as that assigned to similar critical areas in near-by watersheds. The size of the critical area in the Yazoo Highlands, however, is several times that found in adjacent smaller drainage basins to the north and south. The great extent of very serious erosion on local areas and the size of the territory affected cause the Yazoo Highlands to rank first among those areas in the South that are in dire need of soil-protective measures.

The State geologist of Mississippi stated his views of the seriousness of the problem in a speech made February 7, 1922, before the Fourth Southern Forestry Congress at Jackson, Miss.:[1]

> In many of our northern uplands washing of the soil is progressing so rapidly without let or hindrance over large areas that some necessary measures must be adopted soon to arrest the process, otherwise vast areas of formerly agricultural lands will become hopeless wastes. Large areas in at least a dozen upland counties of north central Mississippi have already reached such a condition of soil depletion that they are now hardly suitable for any kind of agriculture, and their taxable values are reduced accordingly.
>
> The erosion of these uplands has resulted not only in enormous losses of valuable agricultural soils but also in concomitant stream filling throughout those areas. Volumes of silt and sand after every heavy shower are poured into the streams from every furrow, gully, and rill that trenches the hillsides, resulting in filling in of their channels. The obliteration of their channels causes overflow of the stream after any considerable rain, with deposition of sand over valuable bottom lands, often doing irreparable damage. Washing hillslopes and sand-filled stream channels are such common features in some of our uplands that the eye of science is not needed to see them—they are features of the landscape, patent to every beholder.
>
> Nor is the damage arising from these conditions limited to the streams of the uplands, for the larger streams suffer in like manner the evil effects extending even into the lowlands of the Yazoo Delta. No remedy applied will be of avail which does not strike at the fountainhead of the trouble—soil erosion of the uplands.

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[1] Dr. E. N. Lowe: Reforestation, Soil Erosion, and Flood Control in Yazoo Drainage Basin. Lumber World Review, Feb. 25, 1922.

The drainage basin of the Yazoo River consists of 12 or 15 counties of north-central Mississippi, the drainage of which is westward through several main channels. The earlier settlers in this region described the country as beautifully rolling woodlands, the forests consisting toward the western parts mostly of hardwoods, toward the east of mixed hardwood and short-leaf yellow pine. Little of the original timber now remains, and large areas have long been cleared and reduced to cultivation. Unfortunately not a little was cleared that was too broken for profitable cultivation, and these areas soon began to wash badly, except where they were carefully terraced.

The agricultural population of the State has never been large enough fully to utilize our agricultural lands. Land, from our earliest history, has been the cheapest thing on the market. Consequently when a hill farm began to wear out, it was thrown out to pasture and more land cleared for crops. These thrown-out lands were never seeded to grasses or terraced to prevent washing, and as a result rapid erosion promptly began. The geological conditions were such as to favor erosion. The soil was derived from a blanketing surface formation of yellowish-brown silt loam a few feet thick, which rested upon stratified sands of great depth.

A pig trail, a mole furrow—any linear depression that concentrated rainfall into the smallest channel down a slope—soon started a gully. As soon as a gully cut through the surface layer of loam into the underlying sand, slumping and caving began, and in an incredibly short time a mere furrow would develop into a deep gorge. The proportions of some of these great chasms, or "caves" as they are popularly called, would astound anyone not accustomed to viewing these destructive results. Chasms 30 to 50 feet deep are by no means unusual, and one was measured by the writer which gave a depth of 160 feet—all in yielding sand, except a few feet of loam capping the hill.

While the cavern just mentioned is of exceptional depth, washes 10 to 20 feet deep are very common, and not infrequently whole slopes, acres in extent, are literally cut to pieces by these growing chasms. Sometimes, if the original slope was quite steep, the process becomes one of stripping, and a naked surface "skinned" of all vestiges of soil, where was once a cultivated field, greets the eye. This destruction presents a desolate and discouraging prospect, and unfortunately these areas are becoming larger instead of smaller from year to year.

It will readily be seen that with large areas in the uplands of this drainage basin undergoing such destructive erosion, rapid stream filling would be inevitable.

RECOMMENDATIONS

A large portion, possibly a quarter or a third (1,600 to 2,200 square miles) of this entire area, in the roughest and most seriously eroded sections, should be made a national forest purchase area, and these Federal holdings should be supplemented by State forests on smaller but still critical portions of the remainder. Although the high percentage of the area in farm ownership (approximately 78 per cent) may render the purchase of such extensive tracts difficult and expensive, this fact should not be allowed to stand in the way of their acquisition.

The National and State forest areas once acquired must first of all be given thorough fire protection. Even occasional wood fires kill young growth, injure and in the end kill other trees, prevent reproduction in the forest, destroy the soil-binding litter and humus on the forest floor, and reduce the density of grass and other vegetative cover where the forest stand is open. Wholesale reforestation is impossible until forest fires are reduced to a minimum.

Where forestry is practiced merely for the sake of producing timber, adequate reproduction of the forest often follows promptly upon protection from fire. On the area under discussion, however, fire protection alone can not reestablish a complete forest cover. The revegetation of bare, eroded slopes and the checking of rapidly ad-

vancing, vertical-sided gullies, offer tremendous problems, the solutions of which have never been attempted in this region.

The main reliance must clearly be placed on vegetation, first to help check the removal of eroded soil from the lower parts of the gullies and bluffs, and later to bind the surfaces of the changing slopes, thus preventing the start of new gullies. Aggressive grasses and vines may serve best in some stages of the work, but the history of the area itself demonstrates that a good forest cover is the best protection in the final stages.

There is urgent need for immediate research to determine not only the most effective but also the cheapest means of checking erosion in this region, for control measures must be applied not only to limited districts but to hundreds and perhaps thousands of square miles of land which now swells the load of silt and of flood water carried by the Mississippi. After the necessary protection forests have been established the utmost care will be needed to keep them at maximum efficiency. This will come about through the application of conservative cutting practices whereby the tree cover is never entirely removed. These forests should produce valuable supplies of timber and perhaps pulpwood also, but the cut must be so regulated that no serious openings are made in the forest cover. Care must also be taken to prevent logging roads from giving erosion a fresh start.

Both within the boundaries of the proposed National and State forests and in the Yazoo uplands as a whole, cultivation should be confined more and more to the level areas and less easily eroded soils. Agricultural practice should be improved in every possible way on these areas. Every effort should be made through extension foresters and the State forestry department to improve conditions on private forest holdings and to reclaim to forest growth the unimproved lands in private ownership. Probably 70 per cent (4,550 square miles) of the drainage should be kept either in forest or in well-sodded, permanent pasture.

JEFFERSON-MADISON-GALLATIN FORKS

(Area 43)

LOCATION AND AREA

The Jefferson, Madison, and Gallatin Rivers form the extreme headwaters of the Missouri River proper, which begins at their junction. The area lies mostly in Montana at its southwest corner and just northwest of Yellowstone Park which itself is partly in this unit.

Area.—Thirteen thousand nine hundred and forty-nine square miles; Montana, 13.274 square miles; Wyoming, 675 square miles.

TOPOGRAPHY

Is strongly diversified by alternating prominent mountain ranges and relatively wide valleys of the major tributaries.

Relative elevations.—Steep broken mountains rising to 8,000, 9,000, and 10,000 feet give place rather suddenly to terraces and benches at

various elevations above the major courses lying between 5,000 and 6,000 feet. Most of area lies between elevations of 5,000 to 7,000 feet, about 10 per cent being below and about 10 per cent above. The lowest portion of the drainage just about reaches 4,000 feet in the vicinity of the juncture of the three rivers. About three-fifths of the unit area is in the valleys with general elevation of from 4,000 to 6,000 feet.

Slopes.—The mountains are distinctly steep, the terraces are gently rolling, and the relatively narrow flood plains are practically flat. The mountain valleys range from narrow canyons to 20 miles in width.

Prevailing exposures.—The aspect is generally northerly, but the exposures are in all directions with no distinct predominance in any direction.

Drainage.—Well developed and distinct for practically all the unit. Especially in the forested mountains the run-off based on physiographic factors is rapid.

Velocity of streams.—There is very little slow-moving water. The mountain streams are rapid and even the main water courses have fairly rapid flow. Normally the velocity is about 1½ miles per hour in the major streams and about 3½ to 4½ miles per hour at flood stages.

Character of streams and stream beds.—The three forks are swift-flowing streams with banks moderately high and gorges for considerable distances. Relatively small portions of the stream banks are low enough for overflow even in spring freshets; these are the very lowest portions of the streams. Stream beds are gravel and rock. After freshets there is only very minor shifting of low-water channels.

These streams are relatively quite constant. High-waters are confined to the normal high-water period of May, June, and earlier, resulting from snow melt in the forested areas and above timber line and the heavy May-June precipitation. The streams are distinctly clear; even in spring high-water they are only slightly colored.

Swamps.—In the Red Rock River Valley are about 10 square miles of swamp, surrounding Red Rock and Swan Lakes. North of Belgrade, Mont., and south of the East Gallatin River are about 24 square miles of swamp, due to seepage from the West Gallatin River. Elsewhere swamp areas are insignificnat.

Natural reservoirs.—Consist of the swamps above described and a few scattered minor lakes throughout the mountain areas. These, however, could hold back only upper headwaters.

Water-storage possibilities.—Storage possibilities are many. A number have been developed by the Montana Power Co.

Topography classification.—Mountains, 40 per cent, 6,000 to 10,000 feet and over; foothills and terraces, 10 per cent, 4,000 to 6,000 feet; rolling, 50 per cent, 4,000 to 6,000 feet.

GEOLOGY AND SOILS

A. *Geological formations.*—In general, the formations in this unit break down into soil material not readily erodible. In the lowland country, generally nonforested, the more important structures are the Fort Union and Lance. The Fort Union is comprised of

light-colored, massive sandstones. The Lance is made up of sandy shales and sandstones. In the mountain or generally forested belts the following formations are most prominent: Igneous rocks, principally quartz marzonite and volcanics; Archean structure, granite, gneiss, and schists; Spokane formation, comprised of quartzites, shales, argillites, and sandstone; Carboniferous, mostly quartzites, sandy shales, and limestones.

B. *Soils.*—Most of the master streams within this unit show influence of local glaciation. Much of the glacial drift has been reworked by stream action. In general, the modified and unmodified drift areas are confined to the nonforest country. Notable exceptions occur in portions of the Big Hole, upper Ruby and upper West Gallatin River watersheds, and in the gravelly range mountains. The glacial and reworked glacial deposits vary greatly in texture in the surface month, ranging from sandy loams to rather heavy clay loams. The sandier phases, however, are in the majority. Rounded to subangular gravels and cobbles are prominent. Surface soils are comparatively shallow, from 8 to 30 inches. The subsoils prevailingly are stony sandy loams, attaining a depth of 3 to 10 feet or more.

In the mountainous or generally forested sections the soils for the most part are residual as to origin and vary from thin to moderately deep gravelly and stony sandy loams to loams in texture.

Erosion within this unit is slight. The erosion that does occur is principally of the sheet and shoestring character.

CLIMATE

A. *Precipitation.*—

(*a*) Average precipitation:

	Inches
1. Yearly average	17.5
2. Theoretically effective flood precipitation—	
(*a*) December–June inclusive	11.0
(*b*) December–February, inclusive, virtually all snow	3.0
(c) March–April	2.5
(*d*) May–June, most direct influence on floods	5.5
3. Snowfall converted into equivalent precipitation at time of its melt—	
(*a*) March–April	0.5
(*b*) May–June	2.5
4. Theoretically effective equivalent precipitation (2) plus (3)—	
(*a*) March–April	3.0
(*b*) May–June	8.0

In the forested mountain 60 per cent of the unit's area lying above about 6,000-foot elevation, the average annual precipitation is about 20 inches, with 6 inches in May and June; the 7 inches or more as snow begins to thaw at lower altitudes in March and gradually extends to higher elevations until completed in late July. Sudden high temperatures and warm rains may hasten the melt for short periods. Excessive rainfall may reach about 12 inches in May and June and may increase the snowfall to about 10 inches.

In the lower valleys, 4,000 to 6,500 foot elevation, the precipitation is about 12 inches during the year, with about 4 inches as snow and about 5 inches in May and June. The snow is usually melted by the end of April. Excessive precipitation may be four times the average, and comes mainly in May and June.

High waters result mainly from the melt of the heavy winter snow, augmented by the heavy May and June precipitation. Sudden high temperatures hasten the snow melt for short periods but ordinarily its disappearance in the forested mountains is gradual.

B. *Temperature.*—

	° F.
1. The mean annual temperature of the unit approximates:	
For lower elevations	44
For higher elevations	38
2. The mean growing season temperature approximates:	
For lower elevations	57
For higher elevations	52

The mean temperatures of the upper and lower regions reflect the varying precipitation and snow-lying qualities of the forested as contrasted to the nonforested areas. Approximately 60 per cent of the area is forested.

HISTORICAL DEVELOPMENT

1. The Three Forks Basin is physiographically different from the other drainages of eastern and central Montana. The wide valleys support some cultivated farms. Grazing lands are principally on the grassy mountain slopes below the margin of forest growth. There is no wide expanse of prairie unbroken by mountains. Over one-half of the area in the Three Forks Basin lies in the timber belt. This belt carries high watershed protective utility.

2. Distribution of wild lands of all classes is entirely due to natural factors, primarily climate and physiography.

3. No appreciable change to the forested region has been brought about by settlement. Farming is confined to the treeless valleys. The line between the grazing land and timberland is sharply defined quite generally throughout the region. No encroachment of one over the other is noticeable. The types are holding their own. The timberlands occur at elevations too high to be subject to agricultural expansion.

Total area of prairie land in Three Forks Basin, 9,026 square miles.

Total area of timbered belt, 6,928 square miles.

The timbered belt is further classified as:

	Square miles
Commercial timber	1, 682
Protective forest and young growth	3, 172
Under forest cover	4, 854
Nonforested lands	2, 074

Ownership of area within timbered region:

	Square miles
Private	625
State	91
National forests	5, 202
Other Federal lands	1, 009
Total	6, 928

Nonforested areas within the timbered belt consist principally of severe exposure where tree growth can not become established. Most of such areas are natural grasslands, others are above timber line and bare of vegetation.

CONDITION OF LANDS OTHER THAN FOREST

A. *Improved lands.*—The aggregate area under cultivation within this unit is approximately 625 square miles; this includes lands in summer fallow, but is exclusive of wild hay lands. About 245 square miles of the hay-land acreage are comprised of tame grasses and only about 8 square miles consist of small grains. The rest of the cultivated land, 380 square miles, is cropped chiefly to the small grains, of which wheat and oats make up the majority.

Both wind and water erosion are light on the cultivated area.

B. *Unimproved lands.*—This unit contains about 10,500 square miles of unforested and uncultivated lands, used largely for pasturage. Of this area about 1,500 square miles are publicly owned State and unreserved and unappropriated Federal lands.

Publicly owned lands.—In its original state the ground cover consisted of a large variety of perennial sod-forming grasses, such as wheat grasses, fescues, grama, sedges, etc. The original ground cover probably averaged a density of about 80 per cent complete ground cover. Continuous unregulated grazing has resulted in a general change of the original cover, and the highly palatable perennials have been reduced quite materially. These have been replaced to a certain extent with less palatable plants of the annual type. The general density of the region is now estimated to be around 40 per cent of a complete ground cover. The reduction of the ground cover has been most marked on steep, wind-swept slopes, and in many places wind, sheet, and gully erosion is now occurring. In the area as a whole the siltage has probably increased around 30 per cent over that of 50 years ago.

There are approximately 500 square miles in Beaverhead County, largely public domain, that are badly overgrazed, and sheet and gully erosion is occurring more marked each year. The same is true regarding about 1,000 square miles in Madison County. These areas would justify a more careful examination to determine the extent of erosion and what remedies can and should be taken to reduce erosion.

Privately owned lands.—Where privately owned lands are fenced in with cultivated areas they are in fair condition and little erosion is occurring. There are, however, considerable areas in private ownership unfenced and these are more or less in the same condition as the public lands.

CONDITION OF FOREST

All of the timbered belt is of the pine type, and essentially protective forest, consisting of lodgepole pine and Douglas fir at the lower elevations, and limber pine and Engelmann spruce in the subalpine range.

The river bottoms are fringed in places with narrow strips of cottonwood and willow, but the acreage involved is very small. The banks of the Madison are treeless after the river leaves the mountains. The hardwoods along the river banks have not been disturbed to any appreciable extent by land clearing, perhaps not more than 5 per cent. Such tree growth is desired on the farms as shelter for the stock. Where tree growth has been removed along the stream courses no bank cutting has resulted.

A. Most of the timbered belt lies within the national forests. Regulated cutting and satisfactory restocking of the logged-off areas insure the perpetuity of the forest cover. Erosion does not take place after logging.

B. The timbered areas in this region are not subject to severe forest fires. Comparatively little has burned since 1889. The acreage denuded by fire on which natural reproduction has not reclaimed the ground is of little consequence.

Protective value of watershed

1. WHOLE UNIT

(*a*) Soil: 100 per cent, at 100, average	100
(*b*) Physiography:	
50 per cent, at	100
30 per cent, at	75
20 per cent, at	50
Average	83
(*c*) Precipitation:	
50 per cent, at	100
50 per cent, at	75
Average	88
(*d*) Character of cover:	
4,854 square miles, at	100
4,172 square miles, at	75
Average	89
(*e*) Forest cover, average	100
Summary of protective value as a whole:	
Soil	100
Topography	83
Precipitation	88
Cover	89
Forest (omitted because already considered under cover).	
Total (average, 90)	360

2. FOREST BELT ONLY

(*a*) Soil		100
(*b*) Topography, average		65
(*c*) Precipitation, average		75
(*d*) Cover:		
Forest, 4,854, at	100	
Other, 2,074, at	75	
Average		92
(*e*) Forest cover only, average		100
Summary: Average of (*a*), (*b*), (*c*), and (*d*)		83

CRITICAL FOREST AREAS

All of the 4,854 square miles under forest cover can be considered critical except about 150 square miles of slightly forested woodland in the public domain.

All these areas are now in good condition; even those outside the national forests have not been injured or affected for lack of protection. The usual national forest protection and administration safeguards that portion by far most important. The public domain and private lands outside are either not in the fire belt or else so inaccessible that no logging of sufficient intensiveness to injure their watershed-protection value has been practiced.

So far as the national forest areas are concerned, no additional effort need be expended on them. They could, however, in several instances be advantageously rounded out by the addition of small parcels of forested public domain lying at or near the forest boundaries. Of the public domain forested lands one parcel in particular, about 100 square miles, which has an influence on stream flow should be assured of permanent protection from fire or destruction otherwise. This lies along the Continental Divide south of Red Rock River. While likelihood of fire is not very imminent, since it lies on a northerly slope, fires occur and as a result its present run-off retarding effect depreciated. The most feasible way to accomplish the result is to add this area to the national forest. This addition would be favored from the standpoint of assuring the best maximum watershed protection. However, it is doubtful if the benefit from such an addition would not be entirely disproportionate to the cost of administration, even considering other possible benefits from national forest control. A sufficiently thorough-going analysis of the situation has not yet been possible to definitely decide this question.

RECOMMENDATIONS FOR WATERSHED

A. *Area to be retained in forest.*—Approximately 4,700 square miles should be retained in forest or about 29 per cent of the total area of the unit.

B. *Measures necessary to keep land productive.*—

1. Continuance of national forest administration and protection on national forests.

2. Several minor additions of public-domain lands to round out existing national-forest units, and possibly the addition of 100 square miles in the Red Rock River Valley.

C. *Other measures.*—Some means should be found to regulate grazing use on unreserved public domain.

THE LITTLE MISSOURI

(Area 44)

LOCATION AND AREA

The Little Missouri Basin is located in southeast Montana, southwest North Dakota, northwest South Dakota, and northeast Wyoming.

The Little Missouri rises in northeastern Wyoming and flows northerly to where it joins the Missouri River in middle-western North Dakota. Its length, by general course, is about 270 miles. The Powder and Yellowstone Rivers lie to the west, the Cheyenne to the south, and the Missouri River to the north and east.

Area.—Nine thousand three hundred and fifty-one square miles:

	Square miles
North Dakota	4, 697
Montana	3, 428
South Dakota	559
Wyoming	666

TOPOGRAPHY

The topography is relatively hard to identify due to its general rolling nature. An appreciable portion of the area is "Bad Lands," described more in detail under "Soils, sequa."

Relative elevations.—The Little Missouri heads at an elevation of about 4,500 and flows into the Missouri River at an elevation of little more than 1,700 feet. About 60 per cent of the watershed has an elevation of between 2,000 and 3,000 feet and 40 per cent of between 3,000 and 4,500 feet. The rugged mountain topography characteristic of parts of the drainages lying to the west is notably absent from this watershed.

Slopes.—The slopes are moderate, and range to flat on the lower flood plains. In the Bad Lands and breaks the moderate slopes are irregularly interspersed by sharp ravines, the slopes of which reach as high as 80 per cent.

Prevailing exposures.—The general exposure is northeast and northwest.

Drainage.—The drainage is northeasterly and not well developed when compared with the drainages of the more mountainous sections. The tributaries are relatively short and parallel the general course of the main stream

Velocity of streams and stream beds.—The streams are moderately fast flowing, the velocity ranging from 1 mile per hour at low stage to 2 miles per hour at flood stage. The average velocity is about 1.5 miles per hour. Banks range from moderately high to low and caving. The stream beds vary from mud silt in the upper reaches to gravel and limestone in the lower section. They contain silt and sand and, in the lower section of the main stream, quicksand. The stream beds in the lower section of the drainage are subject to general shifting during each freshet.

Swamps.—None of consequence.

Natural reservoirs.—None.

Water-storage possibilities.—None, due to the nature of the soil and lack of proper dam foundations.

Topography classification.—Rolling land 40 per cent—elevation 2,500 to 4,500 feet; plains 10 per cent—elevation 1,700 to 2,500 feet; Bad Lands and breaks 50 per cent—elevation 2,500 to 4,500 feet.

GEOLOGY AND SOILS

A. *Geological formations.*—Approximately 2,350 square miles, or 25 per cent, of the unit are embraced by the Bear Paw, Claggett, Colorado, and Pierre shale structures. Upon decomposition these structures give rise to heavy clays. Erosion is heavy.

The Fort Union formation comprises around 5,000 square miles or 50 per cent of the area. Particularly in North Dakota, the upper portion of the formation in a belt about 40 miles wide along the

Little Missouri River, is largely heavily eroded exposing the soft sandstone and shales of the lower part.

B. *Soils—Loams.*—The loams are principally residual in origin and comprise approximately 3,850 square miles, or 41 per cent of the unit. Usually, the surface soil is a brown loam, carrying a small amount of fine sand, or a brown-silt loam, having an average depth of 6 to 10 inches. The subsoil is generally on a yellowish-brown to light-gray loam or silt loam. In some cases the lower subsoil is a heavy, silty clay, while in other sections it is lighter in texture than the surface soil. The heavier subsoils occur chiefly in the hilly or eroded districts; whereas the lighter-texture subsoils are found principally in the undulating-prairie sections. The subsoils attain a depth of 36 inches or more. Both soils and subsoils are usually free from gravel or bowlders.

About 275 square miles along the north boundary of the unit are covered with glacial drift. The surface soil varies from 1 to 2 feet in depth and is a dark brown loam to silt loam. The subsoil is light gray in color and attains a depth of several feet or more. Gravel and cobbles are of frequent occurrence in both soil and subsoil.

The majority of the acreage in the loam type supports a good growth of native grasses. For the most part surfaces are undulating to rolling. Water retention power of the soil is good. Erosion, chiefly of the sheet character, is light except on the hilly or broken areas which comprise possibly 15 per cent of the total loam-type area. The lands in the more rugged type of topography merge into the excessively drained and eroded "Bad Lands" type.

Clay.—Clay covers about 2,300 square miles or 25 per cent of the unit.

The clays usually are deep, from 8 to 10 feet or more, and are very heavy. Surfaces are prevailingly rolling in nature. Plant cover is light. Sheet and gully erosion is very active.

Bad Lands.—This group comprises the excessively eroded and dissected topography known locally as Bad Lands and occupies 3,175 square miles or 34 per cent of the unit. The term refers to the character of the surface, meaning "band lands to travel through."

The general character of these districts is of a minutely dissected and intrenched upland plain, gashed with steep-sided valleys and gullies, interspersed with rounded or flat-topped buttes or hills. Soils vary from loams to heavy clays. The flat-topped buttes and the more gentle slopes are fairly well grassed over. A large percentage of the Bad Lands consist of very steep, practically barren ground. On the whole, erosion is excessive. In the forested sections, notably the Ekalaka, Long Pine, and Short Pine Hills, and the narrow valley bottom along the Little Missouri, the tree growth, while not dense, has an appreciable retarding influence on erosion.

CLIMATE

A. *Precipitation.*—

Average precipitation:	Inches
a. Yearly average	15.0
b. Theoretically effective flood precipitation—	
(1) December–June, inclusive	.5
(2) December–February, inclusive, virtually all snow	1.5
(3) March–April	2.5
(4) May–June, most direct influence on floods	5.5

Average precipitation—Continued.

	Inches
c. Snowfall converted into equivalent precipitation at time of its melt—	
(1) March–April	1.5
(2) May–June	None.
d. Theoretically effective equivalent precipitation, *b* plus *c*—	
(1) March–April	4.0
(2) May–June	5.5

The scattered upland portions of the drainage, more or less wooded, receive 3 to 4 inches more precipitation than the average of the unit. The November to February snowfall of 2 inches is usually gone by April. Periods of excessive precipitation occur spring and fall, when as much as twice the average may be received. High waters are the result of rainfall entirely. The rainfall in summer is often in the form of cloud-bursts—local in extent as a rule.

B. *Temperature*—

	° F.
1. The mean annual temperature of the unit approximates	43
2. The mean growing season temperature approximates	60

Local temperatures within the forest as contrasted with those in the prairie region reflect the usual effects of timber cover in lessening the extremes.

HISTORICAL DEVELOPMENT

1. This basin is principally rough prairie country. Excepting a very small area of sparse yellow pine growth in the western end, the region as a whole is typified as more or less badly eroded waste land, or sparse grazing land.

2. This region has undergone no appreciable change since the advent of man.

3. The forested land areas are confined to the hardwood scrub growth along the streams and gullies, and a small area of yellow pine reserved in the Custer National Forest.

	Square miles
Area within prairie belt	9,116
Area within timbered belt	172
Prairie land within timbered belt	63
Ownership of area within timbered region:	
Private	31
National forests	141
Total	172

4. A great proportion of the Bad Lands in advanced stages of erosion lies in this basin. There is no tree growth save small groups of hardwood brush along gulleys and the courses of the streams.

Other vegetation is sparse and generally lacking on the slopes. This denuded condition is natural and not due to man's activities. Torrential rains and the clay soil contribute to this condition. Vegetation is thin, but that is also true in other regions where erosion does not occur.

Planting of yellow pine on the abandoned Dakota forest has been tried under similar conditions but with no success. Conifer planting seems out of the question because of severe site conditions. Some protective covering can undoubtedly be established, which can hold the soil and perhaps serve as a temporary type for more worth-while

vegetation later on. The possibilities for flood control in this region appear great enough to warrant projecting a study of planting native hardwood brush in the Bad Lands.

CONDITIONS OF LANDS OTHER THAN FOREST

A. *Improved lands.*—Approximately 840 square miles or 9 per cent of the unit is under cultivation. The cultivated-area figure includes lands actually in crop and fallow lands. It does not, however, include the tracts from which native grass hay is harvested. The total tame-hay area aggregates only 85 square miles. Of these about 50 per cent is cropped to grasses and legumes and the rest to small grains. The remaining 755 square miles are farmed almost entirely to the grains. Wheat represents by far the greater acreage. Oats is next in order and corn third.

On the cultivated area erosion from direct run-off is small. As a rule tillage is largely confined to the loam and clay loam soil types. With little exception only the lands having comparatively easy topography are farmed.

Considerable wind erosion occurs on the tilled lands. This is being diminished by the gradual adoption of proper cultural methods.

B. *Unimproved lands.*—The Little Missouri unit contains 8,375 square miles of unforested and uncultivated land used largely for pasture. There are within this area about 800 square miles of public land, State and Federal. The balance, or 7,575 square miles, is in private ownership.

1. *Publicly owned lands.*—In its original state the ground cover consists of a large variety of perennial sod-forming grasses, such as fescues, grama, buffalo, and wheat grasses, and also considerable sagebrush, and had a probable density of about 70 per cent of a complete ground cover. The continuous unregulated grazing at all seasons of the year has resulted in a gradual change in the original cover. The highly palatable perennial plants have been reduced in numbers and in volume and less palatable plants of the annual and weed types have taken their place. The probable density at this time is between 25 and 30 per cent and in many areas the density is reduced to about 20 per cent. The reduction of the ground cover has had a tendency to increase the amount of sheet and gully erosion. Probably throughout this entire area the amount of siltage has increased 30 to 35 per cent over its original state.

2. *Private lands.*—The original ground cover on private lands was entirely similar to that described on public lands. The same conditions generally exist over the private lands, although here and there more care has been taken with stocking and in many cases pasture lands that are fenced in with cultivated lands are in a fair condition.

There are no outstanding critical grazing areas except on the extreme head of the Little Missouri in Crook County. There it is reported that more than 100 square miles along the divide between the Little Missouri and Belle Fourche Creek, mostly on the Little Missouri side, has a ground cover of about 5 per cent, and erosion is becoming very critical. This area is mostly public domain and some measures of control to restore better ground cover should be determined upon.

CONDITION OF FORESTS

The pine type lies in a comparatively small area within the Custer National Forest. These stands are sparsely timbered and intermingled with grazing land. A variety of hardwood brush is found along the stream courses but the area in this type is very small.

The timbered belt comprises so small an area in the whole drainage that run-off is not affected by any changes that might occur in the cover. Reproduction follows logging and fires within the timbered belt.

Protective value of watershed

1. WHOLE UNIT

	Per cent	Protective rating	Weighted average
a. Soil	40	75	60
	60	50	
b. Topography	50	50	65
	40	75	
	10	100	
c. Precipitation	50	50	63
	50	75	
d. Character of cover	35	50	66
	65	75	
e. Forest cover	------------	------------	75
Summary of protective value as a whole:			
Soil 60			
Topography 65			
Precipitation 63			
Cover 66			
Forest (omitted because already considered under cover).			
Total 254	------------	------------	64

2. FOREST BELT ONLY

	Per cent	Protective rating	Weighted average
a. Soil	------------	75	------------
b. Topography	------------	------------	75
c. Precipitation	------------	------------	75
d. Cover:			
Forest	65	75	75
Other	35	75	
e. Forest cover only	------------	------------	75
f. Summary, average of *a*, *b*, *c*, and *d*	------------	------------	75

CRITICAL FOREST AREAS

Only small portions of the pine type can be considered critical. These, consisting of about 125 square miles, are entirely within the National Forests and are adequately safeguarded.

The limited aggregate area of lowland hardwoods occurring as a spotted stringer along the major watercourses can be considered critical. While it does not prevent bank caving or soil washing through high waters it serves to retard their effect both by binding the soil and by slowing up the flow of overflow waters. Its other beneficial effects are negligible.

It is questionable whether the Bad Lands can be considered ever as potential forest lands. Were it possible to plant them to tree or shrub species material benefit would result. They are treated separately.

RECOMMENDATIONS FOR THE WATERSHED

Forest.—1. The area to be retained in forest for essentially watershed protection consists of a small aggregate area of about 40 square miles of wooded bottom land, or less than one half of 1 per cent of the unit area, and 125 square miles of pine type comprising about 1⅓ per cent of the unit area.

2. Measures necessary to keep present forest land productive are under investigation to determine whether it is worth while to control cutting in the lowland hardwood type along the fringes of the major streams. Should this be impracticable through education alone it is doubtful if public acquisition would be worth while.

CRITICAL AREAS OTHER THAN FOREST (SUPPLEMENTAL)

The outstanding generally nonforested critical areas are the Bad Lands in North Dakota extending in a belt along the Little Missouri River and the heavy clay types along the headwaters.

These consist of heavy clay soil areas in various degrees of erosion from slight to the very minutely dissected steep and broken topography of the Bad Lands. The Bad Lands cover about 3,175 square miles. It is impracticable to indicate the extent of the clay soil areas. All but a few areas are critical. Some of them are so situated that they are under cultivation (with irrigation) and others have favorable topographic factors or beneficial admixtures in the soil. On the whole, the clay soils adjoin Bad Lands or have pronounced topography which makes them critical.

The critical clay soil areas and the Bad Lands have a cover of herbaceous vegetation varying from very sparse to none at all. Except for a very small portion of the clay lands which might be reduced to farm-crop production, the only possible economic utility of these areas (fading to negligible in the Bad Lands) is grazing. As a general rule, improperly managed and uncontrolled grazing has lessened any beneficial effect which the grass cover may have had in binding the soil and retarding run-off. In a few localities sparse tree growth of western yellow pine occurs. This is so scattered that it is of little consequence in preventing erosion or run-off.

RECOMMENDATIONS FOR WATERSHED

Nonforest.—Two possible lines of approach toward ameliorating the injurious effects of these areas should be considered.

Where uncontrolled grazing has a material effect, practicability of bringing about control should be looked into. It is not possible with the present hurried, incomplete investigation to arrive at definite conclusions on this point. On private lands this may be accomplished either through State or Federal acquisition or through regulatory State laws. It may perhaps be practicable to put the public-owned lands under some form of control through appropriate congressional action. Among many other foreseen difficulties is the fact that both publicly and privately owned lands that might be acquired are even more scattered than are the critical areas themselves, irrespective of ownership. In spite of these difficulties this

first line of approach will be found to be less unpromising than the second.

The other suggested solution is to plant tree or shrub species on the Bad Lands and on some of the worst of the clay lands where, even without grazing, soil-binding grasses will not thrive. Consensus of opinion of foresters more or less familiar with the question is against the practicability of such attempts. Climatic, meteoric, and soil conditions are predominantly inimical to tree growth. There is, however, enough possibility to justify special investigation, considering the great favorable influence that might result from success in such planting.

MARIAS RIVER

(Area 45)

LOCATION AND AREA

One of the headwater tributaries of the Missouri lies in northwestern Montana, practically against the Canadian line. The Yellowstone River lies to the south and the Milk River to the east.

Area.—Seven thousand and seventy-nine square miles.

TOPOGRAPHY

Elevations.—Three thousand to four thousand feet on river proper, with maximum major tributary elevation of 5,000 feet. At western margin steep mountain slopes rise to 8,000 feet at headwaters. About four-fifths of the unit lies at elevations 3,000 to 5,000 feet.

Slopes.—Comparatively gentle, except at headwaters, where steep. Most of region is elevated rolling plains and prairies lying well above main watercourses.

Prevailing exposures.—Northeast and southeast.

Drainage.—Eastward. Well developed in western portion; not so distinct at lower portions of rolling country.

Velocity of streams.—Main stream normally about 1½ miles per hour, ranging from 3 miles per hour at flood stage to 1 mile per hour at low stage.

Character of streams and stream beds.—Marias River, a swift flowing stream entrenched in valley not over one-half mide wide and 150 to 200 feet below surrounding country; tributary streams likewise are entrenched after leaving steep mountain country. Bed of streams sand, gravel, and some cobble; after freshets minor shifting of low-water channel. In high water becomes turbid after leaving mountains.

Water-storage possibilities.—A number of excellent reservoir sites. For flood waters of upper, principal tributaries. Three large United States Reclamation Service storage projects exist.

Topography classification

	Per cent
Rolling land (3,000–4,500 feet)	75
Foothills and river breaks (4,500–5,000 feet)	18
Mountains (5,000–8,000 feet)	7

GEOLOGY AND SOILS

A. *Geology.*—Approximately 70 per cent of the area within this unit, or about 5,700 square miles, are characterized principally by the Colorado, Claggett, Lance, and Bear Paw geological formations. These formations, upon decomposition, result chiefly in readily erodible soils. Particularly is this true of the Colorado, Claggett, and Bear Paw, which comprise the major part of the four above-named formations.

Practically the entire Marias unit, excepting the narrow fringe of mountains along the Continental Divide in the western extremity, formerly was covered by the continental ice sheet or by local glaciers from the mountainous section.

In approximately the north half of the unit, the glacial drift is fairly deep, averaging 10 to 15 feet or more. Here the underlying formations are not exposed excepting in the mountain fringe along the western edge of the area and for an escarpment of Eagle sandstone in the western part of Toole County.

The southern half of the unit on the whole was only feebly glaciated, and the drift is comparatively shallow. In general, the underlying formations are within 3 to 5 feet or less of the surface. The Colorado and Two Medicine are exposed on the hilltops and along the water courses. Numerous interspersing glacial depressions in the upland sections, however, modify drainage sufficiently that excepting along the master streams, erosion as a result of the formation exposures is not very active.

B. *Soils—Loams.*—This type covers approximately 5,239 square miles, or 74 per cent of the unit. In the northern half of the area, the loams, excepting in the mountains, prevailingly are deep, 10 to 15 feet or more, and vary from gravelly to stony. In the mountains the soil cover is principally a shallow gravelly to stony loam, mostly of residual origin. Erosion is slight excepting on a limited area of nonforest high-plateau country along the base of the mountains. Here sheet and gully erosion on the slopes to the lower ground is fairly active.

In the southern half of the unit, excepting in the mountains and the plateau lands below the foothills, the loams vary from about 3 to 5 feet in depth and carry considerable stone on the surface and throughout the soil mass, especially on the hummocks. The soil ranges from a loam to a silt loam in texture. In the plateau the soils are deep and vary from loams and clay loams in the depressions to gravelly loams on the ridges. The soils in the mountain region are similar in character to those in the mountains of the north half. Erosion in the southern half is light excepting on the slopes in the plateau section and along the breaks into the streams in the more feebly glaciated region to the east. As to the former, the erosion is of the sheet and gully types and is fairly active, whereas in the latter instance it is of the gully form and is rapid.

Clays.—This type covers approximately 1,132 square miles, or 16 per cent of the unit. The clays occur in the glacial-lake depression and along the preglacial stream courses. Depth averages 5 feet or more. In the east central part of Toole County scattering glacial bowlders occur. The rest of the type is free from stone. Due to the generally flat character of the surfaces erosion is slight.

Bad Lands.—This type comprises about 637 square miles, or 9 per cent of the area. The Bad Lands are confined practically entirely to the breaks into the streams, and are comprised either of raw outcrops, principally of the Colorado formation or the resultant heavy clays resulting from the breaking down of the Colorado. Erosion is fairly intense, chiefly in the form of gullying.

Sands.—Embraces about 71 square miles, or 1 per cent of the unit.

CLIMATE

A. PRECIPITATION

(a) Average precipitations

	Inches
1. Yearly average	16.5
2. Theoretically effective flood precipitation:	
(*a*) December–June, inclusive	10.5
(*b*) December–February, inclusive, virtually all snow	2.5
(*c*) March–April	2.0
(*d*) May–June, most direct influence on floods	6.0
3. Snowfall converted into equivalent precipitation at time of its melt—	
(*a*) March–April	2.0
(*b*) May–June	.5
4. Theoretically effective equivalent precipitation (2) plus (3):	
(*a*) March–April	4.0
(*b*) May–June	6.5

For the rolling-prairie area, about three-fourths of the unit, the annual precipitation is about 12 inches, about 5 inches coming in May and June. The light snowfall of December to February is usually melted by April. Excessive precipitation occurs usually in the spring and summer and may reach to one and one-half to two times the average, or up to about 10 inches in May and June.

For the other one-fourth of the unit annual precipitation averages from 15 to 20 inches in the foothills to 20 to 28 inches on the forested mountains. About 5 to 7 inches of this comes in May and June. The snowfall amounts to about 4 to 5 inches. Snow melt begins at lower elevations in April and the higher altitudes are fairly clear by July. Excessive precipitation in any month may reach twice the average, though for any period of several months it will not go over one and one-half times the average.

Flood flows are caused by the rainfall of the spring, augmented by the snow melt at higher altitudes; to a lesser degree by sudden thaws during the last half of the winter.

B. TEMPERATURE

Average temperature: (1) Average annual mean temperature is approximately 41° F. for the lower elevations, 38° F. for the higher elevations. (2) Approximate growing season mean temperature is 56° F. for the lower elevations, 50° F. for the higher elevations.

HISTORICAL DEVELOPMENT

1. Stock raising and dry-land farming are the principal uses of the Marias River Basin. The greatest part is upland prairie, wind-swept plains, with only scanty fringes of hardwood brush along the banks of the large streams, and no other natural tree growth.

Windbreak planting is greatly in demand, but provisions to aid the farmers in this undertaking have been inadequate in the past. Consequently, very little has been done. A few species of hardwood—namely, green ash, caragana, and box elder—can be successfully established in this region without irrigation.

The timbered region lies in the extreme west end of the drainage along the Continental Divide. Most of this timber is within the Lewis and Clark National Forest. Sparse and scattered tree growth extends over the foothills, principally on the northerly slopes, to the edge of the prairie.

2. The condition, character, and distribution of forests and other wild lands is due entirely to the natural factors of climate and physiography. No appreciable acreage has been cleared for agriculture.

3. Practically all of the forest lands within this region are at present growing forests.

	Square miles
Total area in prairie belt	6,438
Total area in timbered belt	641
Timber belt further classified as:	
Commercial timber	12
Protection forest and young growth	360
Under forest growth of all kinds	372
Nonforested lands in timber belt	269
Ownership of area within timbered region:	
Private	4
State	0
National forest	410
Other Federal land (largely national park)	227
Total	641

4. Areas devoid of forest cover within the timbered region are principally natural grasslands on which site conditions are too severe for tree establishment.

CONDITION OF LANDS OTHER THAN FOREST

A. *Improved lands.*—The total area in cultivation within the Marias unit exclusive of lands from which wild hay is cut is approximately 780 square miles; this figure includes lands in summer fallow. Hay and the small grains are the chief crops. Of the hay crop about 50 square miles are comprised of tame grasses and 15 square miles of small grains. The remaining cultivated area, aggregating about 715 square miles, is cropped mostly to wheat.

B. *Unimproved lands.*—The Marias unit contains about 6,000 square miles of nonforested and noncultivated lands, used largely for pasturage. Of this area there are about 150 square miles of publicly owned State and unreserved and unappropriated Federal lands. It contains also about 2,500 square miles of Indian and national park lands and about 3,350 square miles of privately owned lands.

Publicly owned lands.—In its original state the ground cover consisted of a large variety of perennial sod-forming grasses, such as wheat grasses, fescues, grama, and buffalo, having a density of about 80 per cent complete ground cover. Continuous unregulated grazing has resulted in a gradual change of the original cover. The highly palatable perennials have been reduced quite materially and less

palatable plants of the annual type have appeared in their stead. The general density has been reduced to 60 per cent of a complete ground cover, the steeper wind-swept slopes suffering more than the flat or gentle slopes. The above condition has brought about increased wind, sheet, and gully erosion, which is estimated to amount to about 20 per cent more now than 50 years ago.

Indian and park lands.—The general type of ground cover on this class of lands was originally very similar to those described above. Due to regulated grazing in the case of Indian lands and to no grazing to speak of on the park lands, conditions are little changed as to ground cover and run-off.

Privately owned lands.—The original ground cover was entirely similar to that described on publicly owned lands, and while here and there are areas where conservative stocking has been practiced by the owner, the general conditions are not a great deal different than those described as existing on publicly owned lands.

CONDITION OF FOREST

A. *In forested belt.*—Of the 378 square miles of forested lands, 13 square miles support commercial timber, 45 square miles are cut-over and burned areas reproducing, and 320 square miles are purely protection forests; all pine type.

(*a*) *Effect of lumbering.*—Very small portion has been logged. In last census (1924) only one small sawmill operating. Such logging does not denude the cut-over areas, but only temporarily thins the protective cover, since natural reproduction follows.

(*b*) *Effect of fire.*—Fires denude only temporarily, since natural reproduction follows. Eroded slopes very rare; attributed in part to generally light run-off. But few fires in this territory.

(*c*) *Effect of grazing.*—No detrimental effect results from grazing within the forested section. Government control generally safeguards overgrazing.

(*d*) *General summary of forest conditions.*—Forested area in good condition as regards its effects on stream flow and erosion.

B. *In nonforested belt.*—Scattered tree growth interspersed in range land has been cut for fuel and fence posts only. The influence of these trees before cutting was immaterial so far as erosion and run-off are concerned.

All of the timbered belt is of the pine type, most of which is purely protective forest cover. Lodgepole pine predominates, followed by Engelmann spruce and Douglas fir. Ranches in the foothills have range land interspersed with scattering tree growth. No figures are available of the area in river-bottom hardwoods. This area, however, is small and plays no important part in stream flow. Bank cutting was especially noticeable this year. It was attributed to excessive high water and not to any removal of the fringe of hardwoods along the banks. This hardwood growth has not been disturbed by man to any appreciable extent. Cottonwood, green ash, and box elder are the species commonly found along the river courses of this region.

Effect of lumbering.—Logging in the sparsely timbered foothills has denuded areas of tree growth to a small extent and grass encroached upon it. Erosion has been of no consequence. In the

truer forest type at the higher elevations, natural reproduction follows removal of the timber. No denuded areas have resulted.

Effect of fire.—Forests of this region are only to a very little degree subject to severe fires. Areas so affected are only temporarily denuded. Reproduction follows. Eroded slopes are rarely found in this and similar regions of Montana. This is attributed not so much to the condition of the ground cover as the light rainfall of the region.

Protective value of watershed

1. WHOLE UNIT

(*a*) Soil:	
1,132 square miles, at	50
650 square miles, at	50
42 square miles, at	100
5,368 square miles, at	75
Average	69
(*b*) Topography:	
5,400 square miles, at	75
1,300 square miles, at	50
493 square miles, at	50
Average	69
(*c*) Precipitation	75
(*d*) Character of cover:	
378 square miles, at	100
6,815 square miles, at	75
Average	76
(*e*) Forest cover, average	100
(*f*) Summary of protective value as a whole:[1]	
Soil	69
Topography	69
Precipitation	75
Cover	76
Average	78.5

2. FOREST BELT ONLY

(*a*) Soil	100
(*b*) Topography, average	75
(*c*) Precipitation, average	75
(*d*) Cover:	
Forest, 378, at	100
Other, 273, at	75
Average	88
(*e*) Forest cover only, average	100
(*f*) Summary, average of (*a*), (*b*), (*c*), and (*d*)	84.5

[1] Forest omitted because already considered under cover.

CRITICAL FOREST AREAS

An area of 378 square miles in Lewis and Clark National Forest and extreme western edge Blackfeet Indian Reservation and Glacier National Park. Federal Government and various agencies are doing all that is practicable to maintain these tracts in good condition for watershed protection. Classed as beneficial area.

RECOMMENDATIONS FOR WATERSHED

A. *Area to be retained in forest.*—The present area 378 square miles, or 5.3 per cent of drainage.

B. *Measures to keep forest land productive.*—Practically all that is necessary is being done.

C. *Grazing land.*—More conservative use and proper management of livestock are necessary.

D. *Bad Land areas.*—General studies are needed to find some kind of vegetation to bind the soil, and to ascertain how to stop erosion.

MILK RIVER

(Area 46)

LOCATION AND AREA

Unit lies against the Canadian boundary in north central Montana. Milk River heads in northeastern Montana near the Canadian boundary and flows in a northeasterly direction, crossing the international boundary at longitude 113° west, thence it flows in a southeasterly direction reentering the United States at longitude 110° 45′ west and continuing in a southeasterly direction to where it enters the Missouri River in northeastern Montana.

The Marias and upper Missouri Rivers lie to the south while the lower Missouri River drainage lies to the east.

Area.—The Milk River drainage in the United States consists of 15,042 square miles, while the area in the Dominion of Canada is about 10,000 square miles.

TOPOGRAPHY

The headwaters of the Milk River rise to an elevation of 7,000 feet. The stream flows into the Missouri at an elevation of 1,900 feet. Of the area, 4 per cent is mountainous with elevations ranging from 4,000 to 7,000 feet, and 96 per cent of the area is between 1,900 and 4,000 feet elevation, and consisting of a wide expanse of plains and rolling country.

Slopes.—The slopes are comparatively gentle on the plains and rolling country, while in the mountainous regions the slopes are steep.

Prevailing exposure.—The prevailing exposure is southeast and northeast.

Drainage.—The drainage is not well defined on account of the gentleness of the topography except in the small portion of mountain-

ous country. The general drainage is easterly. The tributaries entering from the south are short, while those entering from the north are relatively longer. All these tributaries enter the main stream at right angles to its course.

Velocity of streams.—The main Milk River normally has a velocity of 1½ miles per hour, ranging from 2½ miles per hour at flood stage to over 1 mile per hour at low stage. The flow in the tributaries resembles very closely the flow in the main channel.

Character of streams and stream beds.—In the headwaters of the Milk River and tributaries the banks are low and the bottom gravelly. In the main stream throughout its middle course the banks are high and the bed is quicksand. In its lower course the banks are low and subject to partial overflow, with bed of quicksand. After freshets there is minor shifting of low-water channel. Through most of its course the stream is very meandering and slow.

Water-storage possibilities.—On North Fork of Milk River, 86,000 acre-feet, Paradise Reservoir containing about 3,600 acre-feet; Snake Creek Reservoir, containing about 6,000 acre-feet; Big Sandy Reservoir, containing about 48,000 acre-feet.

The above sites are being considered for development by the United States Reclamation Service.

Topography classification.—Plains, 90 per cent, elevation 1,900 to 3,500; rolling land, 6 per cent, elevation 3,500 to 4,000; mountainous, 4 per cent, elevation 4,000 to 7,000.

GEOLOGY AND SOILS

A. *Geological formations.*—The following structures comprise around 8,700 square miles or 57 per cent of that portion of the Milk River drainage within the United States: Bear Paw, Clagget, Colorado, and Lance. Of the four formations in question the Bear Paw makes up by far the greater percentage. The weathering of each results chiefly in heavy clay soils. The remaining formations in this unit, principally Judith River and Two Medicine and the Archean and Paleozoic rocks in the Bear Paw and Little Rockies Mountains, give rise chiefly to soils which have fair to good water absorption power and which are not readily erodible.

Practically the entire unit excepting the Bear Paw and Little Rockies Mountains area was covered to varying depths by glacial drift and to a lesser degree by glacial and recent stream deposits. To the south of Milk River on the Bear Paw formation, around 2,250 square miles, glaciation was rather feeble. As a consequence the formation is exposed over much of the area in the form of barren hills having a high degree of erodibility. The larger creeks usually are bordered by alkali flats.

To the north of Milk River the drift overlies the formations for the most part to a depth of 25 feet or more. Exceptions occurs particularly along the flood plain of the Milk and the breaks into some of the master side creeks. Where the drift has been eroded away the heavy clays in the form of gently sloping tracts to rough bad lands are found. The drift-covered uplands are characterized by a billowy, hummocky surface relief. In the northeastern part of Blaine

County and extending to the northwest part of Phillips County is a group of isolated plateaus rising about 300 feet above the level of the glacial plains. On the eastern and southern slopes of these benches the Bear Paw and Lance formations are exposed in the form of escarpments.

B. *Soils.*—Loams make up about 11,361 square miles or 75 per cent of the United States portion of the unit. The type varies from rather shallow on the higher ridges to a depth of 25 feet or more on the more gently rolling sections. Textures vary from sandy loams to loams. Gravel and bowlders occur in varying percentages but usually not in sufficient quantities to warrant a classification as gravelly or stony loams. Little erosion except on the higher divides and along intermittent stream courses is taking place. It is chiefly of the sheet and shoe-string character.

Clay comprises about 1,955 square miles or 13 per cent. The clays usually exceed a depth of 5 feet. In general, erosion in the form of gullying and bank caving is heavy. The vegetation consists of a thin stand of mostly black sage.

Bad Lands.—Comprise about 1,651 square miles or 11 per cent of the unit. The Bad Lands consist principally of raw exposure of shales and to a lesser degree sandstones. There is ordinarily little actual soil development. Where it does exist it is generally a heavy clay. Erosion is heavy.

Sands.—Cover 75 square miles, or less than 1 per cent of the unit.

CLIMATE

A. PRECIPITATION

Average precipitation

	Inches
1. Yearly average	14.5
2. Theoretically effective flood precipitation:	
(*a*) December–June, inclusive	8.5
(*b*) December–February, inclusive, virtually all snow	1.5
(*c*) March–April	2.0
(d) May–June, most direct influence on floods	5.0
3. Snowfall converted into equivalent precipitation at time of its melt:	
(*a*) March–April	1.5
(*b*) May–June	0.0
4. Theoretically effective equivalent precipitation, (2) plus (3):	
(*a*) March–April	3.5
(*b*) May–June	5.0

While the forested mountain precipitation is about one-half higher than the average, it is of little influence because of the limited area. The 3 inches of snow is usually gone by the end of March. Except for occasional sudden thaws in the spring, the high waters are the result of the 5-inch May-June precipitation. Excessive precipitation may reach twice the average, especially in spring and summer months.

B. TEMPERATURE

1. Mean annual temperature approximates 41° F.
2. Mean growing season temperature approximates 59° F.

HISTORICAL DEVELOPMENT

1. The land in this vast drainage is largely used for stock raising and dry-land farming. Much of it has little use as yet and is untenanted. The region is principally prairie land. No forests of any consequence occur in this basin.

2. The causes responsible for its present condition, character, and division into prairie and timberland are natural. Climatic and physiographic conditions determine the limitations of type.

3. The condition of the forest land is unchanged. Small stands of forests occur on the divide between the Milk and Missouri Rivers.

	Square miles
Total area in prairie belt	14,731
Total area of timber belt	311
The timbered belt is further classified as:	
Commercial timber	66
Protection forest and young growth	243
Under forest cover	309
Nonforested land	1
Ownership of area within timbered region:	
Private	64
National forests	40
Other Federal lands	206
Total	310

Most of the 40 square miles of timber belt in the Fort Belknap Indian Reservation is in Indian allotments. This has not been disturbed by logging and has sustained only light fire damage.

CONDITION OF LANDS OTHER THAN FOREST

(*a*) *Improved lands.*—The total area now in cultivation within the unit is about 1,360 square miles. This includes lands in fallow as well as lands actually in crop, but does not include the acreage of native grasses from which hay is cut. The acreage of tame grass and legume hay is about 65 square miles. Around 35 square miles of small grains are cut for hay. The remaining cultivated area aggregating 1,260 square miles is cropped mostly to wheat and oats. Corn is an important crop in the extreme east portion of the unit. Considerable difficulty has been experienced from wind erosion resulting largely from a clean summer fallow. Duckport cultivators which leave a clod mulch, thus greatly reducing soil blowing, are rapidly repacing former cultivation implements in preparing the land for seeding and summer fallow. On the cultivated areas, virtually all of which are confined to the lighter textured soils having easy topography, erosion resulting directly from run-off is light.

(*b*) *Unimproved lands.*—This unit contains about 13,500 square miles of unimproved nonforested lands used largely for pasturage. Of this area there is 7,819 miles of publicly owned lands (State unappropriated, Government, and Indian reservations). The balance, or 5,681 square miles, is in private ownership.

Publicly owned lands.—Originally this area was well sodded with highly palatable perennial grasses such as a large variety of wheat grasses, fescues, grama, and buffalo, with but few weeds and nonpalatable plants. The average density was probably 75 per cent of a complete ground cover. The continuous grazing and in many

places overgrazing and premature grazing has resulted in an intrusion of many nonpalatable annual plants, both grass and weeds, and a reduction of the perennial highly palatable plants. The average density at present is probably near 50 per cent of a complete ground cover with a reduction in grazing capacity of 30 per cent over the original conditions. Slow deterioration of the perennial and most palatable grasses is in progress at the probable rate of 1 per cent per annum.

The effect of the reduction of perennial plants and the density of the ground cover on the annual run-off is obvious. In this, as on most areas where unregulated grazing is practiced, the greatest reduction in ground cover occurs on the steeper slopes, which also contains the poorer soils, resulting in rapid run-off and an increase of wind, sheet, and gully erosion.

Because of the change in ground cover on the area in question, it is estimated that the silt carried by the streams within the area has increased 25 per cent or more over that of 50 years ago, and with the present rate of deterioration of the perennial types of grass ground cover that silting will probably increase more rapidly in the future than in the past.

Privately owned land.—Private ranges in some instances are in good condition, while in others conditions are even worse than the publicly owned range, but on the whole there is only a slight difference.

CONDITION OF FOREST

The total area under forest cover is classified as pine type. The principal species are western yellow pine and Douglas fir. No figures are available of acreage in the stream bottoms supporting hardwoods and brush. However, this acreage is comparatively small. Narrow fringes of cottonwood grow on the river banks but do not extend away from the streams. Cottonwood and willow predominate. Not more than 20 per cent of this growth has been cleared along the stream bottoms for farming. Cutting away of the banks has occurred to some extent but this is not caused by removal of trees as much as excessively high water. In high water banks are cut where tree growth is established.

A. *Effect of lumbering.*—Very little lumbering is done in this region. The thinly populated district within reach of the supply requires little. Removal of timber is quickly followed by natural reproduction except on the sparsely wooded grass slopes where restocking is slow and sometimes fails. Erosion rarely occurs.

B. There are no areas in the pine type denuded by fires. Forest fires are infrequent and the damage done has been only temporary. No serious erosion takes place.

Protective value of watershed

WHOLE UNIT

(*a*) Soil:	
75 per cent of area, at	100
13 per cent of area, at	50
11 per cent of area, at	50
1 per cent of area, at	100
Average	88

(*b*) Topography:	
90 per cent of area, at	100
60 per cent of area, at	75
40 per cent of area, at	50
Average	96.5
(*c*) Precipitation, average	75
(*d*) Character of cover:	
2,500 square miles, at	50
315 square miles, at	100
12,432 square miles, at	75
Average	72
(*e*) Forest cover, average	100
(*f*) Summary of protective value as a whole:[1]	
Soil	88
Topography	96
Precipitation	75
Cover	72
Total	331
Average	83

FOREST BELT ONLY

(*a*) Soil	100
(*b*) Topography, average	50
(*c*) Precipitation, average	75
(*d*) Cover—	
Forest, 314, at	100
Other, 1, at	75
Average	100
(*e*) Forest cover only, average	100
(*f*) Summary, average (*a*), (*b*), (*c*), (*d*)	80

CRITICAL FOREST AREAS

Small acreage now has a beneficial effect, but it amounts to nothing on account of the limited area involved.

Present condition is good, and all reasonable effort is being made by Federal agencies to keep it so.

RECOMMENDATIONS FOR WATERSHED

A. *Area to be retained in forest.*—Three hundred and nine square miles.

B. *Measures necessary.*—Continuance of present activities by Government agencies in protection and administration. Permanency to be assured.

CRITICAL AREAS OTHER THAN FOREST (SUPPLEMENTAL)

These consist of heavy clay soil areas in various degrees of erosion from slight to ultimate in the form of very minutely dissected steep

[1] Forest omitted because already considered under cover.

and broken topography, known as Bad Lands. The areas occur in compact bodies in some places but they are commonly situated along the breaks of the main water courses where the stream has cut its way through the more readily erodible formations exposing them to water and, to a less degree, wind action.

The Bad Lands amount to about 1,625 square miles. Of the clay-soil areas it is impracticable to indicate the extent. Only a portion of the areas of clay soil are critical; some of them are so situated that they are under cultivation (with irrigation) and others have favorable topographic factors or beneficial admixtures in the soil. On the whole, the clays are critical where clay soils adjoin Bad Lands or where the topography is pronounced.

The critical clay-soil areas and the Bad Lands have a cover of a herbaceous vegetation varying from very sparse to none at all. Not even sparse tree growth occurs; this is so scattered that it is of little consequence in preventing erosion or run-off.

With the exception of a limited portion which can practically be reduced to farm crop production, the only possible economic utility of these areas, fading to negligible in the Bad Lands, is grazing. As a very general rule improperly managed, uncontrolled grazing has depreciated materially such beneficial effect in soil binding and run-off retarding as these grasses may have had.

Noteworthy among the Bad Lands and the badly eroding heavy clay soil areas are blocks on Larb and Willow Creeks south of the main Milk and on Willow Creek north of the main Milk. Both these blocks are principally from the Claggett and Bear Paw structures.

RECOMMENDATIONS FOR WATERSHED (SUPPLEMENTAL)

Two possible lines of approach toward ameliorating the injurious effects of these areas should be considered.

Where uncontrolled grazing has a material effect, practicability of bringing about control should be looked into. On private lands this may be accomplished either through State or Federal acquisition or through regulatory State laws. The public-owned lands should be brought under some form of Federal control. Among many other difficulties that are foreseen is that the public-owned lands and the private-owned lands that might be acquired are even more scattered than are the critical areas themselves, irrespective of ownership. In spite of these difficulties this first line of approach will probably be found to be less unpromising than the second.

The other suggested solution is to plant tree or shrub species on the best of the Bad Lands and on some of the worst of the clay lands where even without grazing soil-binding grasses will not thrive. Consensus of opinion of foresters more or less familiar with the situation is against the practicability of such attempts. Climatic, meteoric, and soil conditions are predominantly inimical to tree growth. There is, however, enough possibility to justify special investigation, considering the great favorable influence that might result from success in such planting.

MIDDLE MISSOURI RIVER

(Area 47)

LOCATION AND AREA

Lies in extreme northeastern Montana, west half of North Dakota, and northwest portion of South Dakota. From the mouth of the Milk River the Missouri River runs eastward well into North Dakota, thence southeasterly and south into South Dakota.

The Milk and upper Missouri River units lie to the west, the Yellowstone to the south, the Little Missouri to the west, the Red and James Rivers to the east, and the Cheyenne River to the south.

Area—

	Square miles
North Dakota	27, 721
South Dakota	14, 817
Montana	10, 165
Total	52, 703
Dominion of Canada	2, 599

TOPOGRAPHY

The topography in this unit is not well defined. The area is chiefly narrow (about 5 miles) flood-plains areas along the river proper with relatively narrow strips of " breaks," gradually changing to rolling land farther back from the main stream and along its tributaries.

Relative elevations.—In the lower Missouri River drainage the altitude ranges from 3,500 feet to about 1,500 feet near the mouth of the Cheyenne River. About 5 per cent of the area lies above 3,000 feet, the largest part of which lies in the extreme southwest part of the unit and in the northwestern part of South Dakota; 80 per cent of the area lies between 2,000 and 3,000 feet, 15 per cent lies between 1,500 and 2,000 feet elevation and includes the flood plain of the main stream and the extreme southeastern portion of the unit.

Slopes.—The slopes range from relatively moderate to flat. However, exceptions to these slopes are found along sharp draws where the slopes reach 60 per cent for relatively small areas, and along the breaks of the main watercourses. North and east of the main river in North Dakota the heavily glaciated country is full of depressions with no connected drainage.

Prevailing exposure.—The general aspect on the upper portion of this unit is southeast and northeast; in the lower portion the exposure is to the east and west.

Drainage.—The general drainage is southeast; the tributaries coming from the south and west are relatively long and enter the main stream almost at right angles to its main course. To the north and east in North Dakota the area is narrow with very poorly defined drainage.

Velocity of streams.—The velocity of the main stream at low stage is 1 mile per hour while under extreme flood stage is 4 miles per hour. Normally it flows 2 miles per hour. These figures represent the characteristic flow of its tributaries.

Character of streams and stream beds.—The main stream is rather sluggish and meandering, the banks range from moderately high to low and caving. The bed is composed of gravel and sand which shifts, forming bars and shoals during high-water stages. Through quite a proportion of their length the main river and major tributaries are entrenched, the flood plain, 1 to 5 miles wide, being flanked with " breaks."

Water storage possibilities.—None.

Topography Classification.—

	Per cent of area	Elevation
		Feet
Rolling land	35	2, 500–3, 500
Plains	65	1, 500–2, 500

GEOLOGY AND SOILS

A. *Geological formations.*—The principal structure is the Fort Union, covering about 35,740 square miles, or 68 per cent of the total area within the unit. In the upper part this formation gives rise chiefly to loam soil types having excellent water absorption power. In a number of places, although of proportionately small aggregate area, the soft shales and sandstones of the Fort Union in the lower part are exposed. The soil material resulting from these is readily erodible. Approximately 50 per cent of the Fort Union formation is covered by glacial drift varying from a few feet to 100 feet in depth.

The Lance aggregates 9,135 square miles, or about 17 per cent of the area. Around 70 per cent of the Lance is covered to a considerable depth by glacial drift from the continental ice sheet. In general, the Lance forms clay loam to clay soils. In the heavier phases, particularly on areas of relatively stony surface, relief erosion is severe.

The Pierre shale comprises about 5,720 square miles, or 11 per cent of the unit. For the most part the weathering of the Pierre results in a heavy sticky clay that is readily erodible. About 3,250 square miles of the Pierre shale structure are covered with glacial drifts.

The Bear Paw structure embraces about 800 square miles. It gives rise to heavy clays. All of the Bear Paw, however, excepting a few narrow belts along stream courses, are covered with glacial drift to a depth of 15 feet or more.

The remaining, approximately 1,308 square miles, are comprised chiefly of the following structures, given in their relative order of importance as to area: Quaternary alluvium, Fox Hills, and White River.

B. *Soils—Loams.*—Approximates 46,578 square miles, or 89 per cent of the unit. Of this type around 17,800 square miles are comprised of principally residual material, the alluvial or other phases aggregating not to exceed 10 per cent. The surface soils principally are loams. In places the surface mantle consists of a fine, sandy loam. This surface material, generally brown in color, usually extends to the depth of 6 to 10 inches, where it rests usually on a yellow-brown to gray loam or silt loam. In places the subsoil varies

from light textured, fine sandy loam to heavy, silty clays. The subsoil as a rule is comparatively deep, averaging 3 to 5 feet or more. Erosion on the residual types is normal.

Approximately 29,000 square miles were covered by glacial drift, which consists of material having a depth of from a few to more than 100 feet. In general the drift area gives rise to dark brown surface soils, typically loams or silt loams attaining a depth up to 2 feet. The subsoil is principally a light gray comparatively deep calcareous material. Rounded or subangular pebbles, cobbles, or boulders frequently occur in both the surface and subsoils. The soils of the glacial drift type are sufficiently open to absorb readily the water from rains and snows. Aside from occasional limited areas in which the gravel extent is high the subsoils are retentive of moisture. Where dissected by coulee or stream valleys the glacial soils are somewhat subject to erosion but usually this type in its native condition is well protected by sod. Under cultivation it is not subject to injury from gullying or washing except along the more pronounced slopes.

Clays.—Approximately 3,309 square miles, or 6 per cent of the area. The principal clay type is known as the Pierre, which is derived by weathering from chiefly the Pierre and graneros shales. The Pierre clay covers about 2,090 square miles. The most distinguishing characteristic is its heavy sticky mixture. The surface soil in texture ranges from a silty clay loam through a silty clay to a heavy clay, and is usually a yellowish brown to dark brown in color. The subsoil which is encountered at a depth of 6 to 10 inches is a silty clay to heavy clay of a gray to yellowish-brown color. Soft shale as a rule is encountered at 3 to 6 feet below the surface.

The surface of the Pierre clay is gently rolling to very hilly and broken; in some cases, as along the Missouri River, even approaching the character of Bad Lands. In general the surface relief is properly classified as decidedly rolling. The drainage channels have cut out comparatively deep valleys with rounded ridges between. The grass cover varies from fairly dense to exceedingly sparse. The Pierre, owing to its character, is of a high degree of erodibility, and in general considerable erosion is taking place. Where the typography is very broken, erosion has been very active, much of the surface soil has been removed, and the subsoil, where washing has been most pronounced, leaves the soft shale exposed.

Of the remaining 1,219 square miles of clays within the unit, about 700 square miles also are of residual origin, and 519 square miles represent alluvial deposits. These soils are comparatively deep, 3 feet or more. The residual type prevailing is heavy, whereas the alluvial phase varies from a clay loam to compact clay. The surfaces are fairly level and erosion is moderate excepting in the alluvial type. Here bank caving, especially along the main Missouri, is fairly active.

Bad Lands.—Approximately 2,289 square miles, or 4 per cent of the area. They are comprised of heavily eroded silty to heavy clay types over principally shale formations. The soil varies from comparatively deep to a thin to practically negligible covering over the raw rock exposures. The Bad Lands are characterized by a steep topography, broken by numerous sharp gullies and valleys. Plant

growth is sparse to absent over much of this type. Erosion of the sheet and gully character is very heavy: Gravels 30 square miles and sands 25 square miles.

CLIMATE

A. PRECIPITATION

(*a*) *Average precipitation:*

	Inches
1. Yearly average	17.5
2. Theoretically effective flood precipitation:	
(*a*) December–June, inclusive	10.5
(*b*) December–February, inclusive, virtually all snow	2.0
(*c*) March–April	2.5
(*d*) May–June, most direct influence on floods	6.0
3. Snowfall converted into equivalent precipitation at time of its melt:	
(*a*) March–April	2.0
(*b*) May–June	
4. Theoretically effective equivalent precipitation (2) plus (3):	
(*a*) March–April	4.5
(*b*) May–June	6.0

(*b*) *Distribution of precipitation.*—Snow falls from December to March and is usually entirely gone by mid-April. Excessive precipitation occurs mainly in the spring and early fall months. It may amount to three times the average for the period though seldom reaching one and one-half times the annual average.

The rain often comes in the form of localized thundershowers or cloudbursts.

B. TEMPERATURE

1. The mean annual temperature of the unit approximates 40° F.
2. The mean growing season temperature approximates 59° F.

These low average temperatures reflect the open prairie-type climate. Extreme temperatures occur and the temperature range in any locality is rather great. Temperatures fluctuate rapidly at all seasons of the year.

HISTORICAL DEVELOPMENT

1. This entire basin is naturally upland prairie, the major portion used as grazing land for stock raising with about 25 per cent of the area under cultivation.

2. Forested areas have not been changed materially by settlement in this region. River-bottom hardwoods have been removed in the small towns along the river courses but the total acreage of forest cover thus lost is very small. The distribution of timber is determined by natural causes, principally climate and physiography. About 13,500 square miles of the natural prairie have been put under cultivation.

3. The pine-timbered belt is very small and affects this region in no material way. Sparse western yellow pine is found in the Sioux division of the Custer National Forest of South Dakota. There are 132 square miles in this pine-timber belt, but nearly half of this area is grazing land dispersed with the timber. This timber belt is comprised of 20 square miles in private ownership and 112 square miles within the boundaries of the Custer National Forest.

Other tree growth is principally of the river-bottom hardwoods type with very small proportion of shelter-belt and about 35 square miles of upland hardwood thrown in with this. This aggregates about 250 square miles.

The lowland hardwoods are in spotted stringers along the major water courses, relatively narrow, but as much as 5 miles wide in some limited spots.

4. The nonforested areas within the forest belt are natural grazing lands. In recent years there has been very slight marginal extension of the forests over these natural openings. Site conditions are severe, however, for tree establishment in these openings.

About one-twelfth of the prairie land is waste land, although it is not as rough as the Bad Lands. This area plays an important part in Mississippi River sedimentation. Erosion is extensive. It is thought there may be a possibility that much of this land can be protected by native hardwood planting. Under the hardwoods nurse crop some conifers may later thrive. Encouragement in this is lent in the extension of the natural western yellow-pine growth now taking place. It is a field for further investigation.

CONDITION OF LANDS OTHER THAN FOREST

(*a*) *Improved lands.*—The total area under cultivation in this unit aggregates 13,500 square miles. This includes lands in fallow as well as areas actually in crop. It is, however, exclusive of lands supporting native grasses from which hay is harvested. The tame hay area is small, comprising only about 700 square miles. Of this about 460 square miles are in grasses and legumes and 240 square miles in small grains. The remaining 12,800 square miles are cropped chiefly to the grains, of which wheat is the outstanding crop throughout the entire unit. In the Montana and South Dakota portions, corn ranks second in area, followed by oats and flax. In North Dakota oats rank second to wheat in area. Barley and rye together aggregate a much greater area than corn.

The cultivated area is approximately 25 per cent of the total area within the unit. As a rule cultivation is confined to the more nearly level to gently sloping or undulating lands. Without question the degree of erosion from run-off direct on these areas is greater than would be the case if they were in their native grass-covered state. However, such erosion as does occur from run-off direct is less important than that caused by wind, and is relatively unimportant compared to the excessive water erosion that occurs on the nontilled badlands and heavy clays.

(*b*) *Unimproved lands.*—The Lower Missouri unit contains about 38,900 square miles of nonforested, noncultivated lands used largely for pasturage. Of this area about 600 square miles are publicly owned. These lands are State and Federal lands, unreserved and unappropriated. About 28,900 square miles are in private ownership.

Publicly owned lands.—In its original state the ground cover consists of a large variety of perennial, sod-forming grasses, such as grama, fescues, wheat grasses, and also considerable areas of sage-

brush. Before the advent of settlement in this region the density of ground cover was probably between 75 and 80 per cent of a complete cover. Because of unregulated grazing in the earlier days, a gradual change has taken place, although not so pronounced as in many other grazing areas. The highly palatable perennials have been reduced and in their place unpalatable annual plants have come in their stead. The average density at the present time is probably 60 per cent of a complete ground cover. Naturally the steeper, wind swept slopes have suffered most in this type of country. Sheet and gully erosion has taken place to a certain extent, and unless a vegetative cover is reestablished it will increase as the years go by.

Privately owned lands.—The original ground cover on the private land was very similar to that described on publicly owned land. Because of the establishment of a herd law in North and South Dakota the private lands have not suffered as much from overgrazing as have the public lands and are now in a fairly satisfactory condition.

FOREST CONDITIONS

Western yellow pine, the only conifer growing in this basin, is confined to the rims of the mesas. The stands are sparsely stocked and contain principally young age classes. The river bottoms are fringed with hardwoods, most important of which is cottonwood. The fringe along the Missouri widens as the river flood plain becomes broader toward its mouth. The very small amount of timber logging or destruction by fire in either pine or lowland hardwood type in this region has not affected the influence of the timberland on run-off in the drainage.

PROTECTIVE VALUE OF WATERSHED

1. WHOLE UNIT

(*a*) Soil:	
91 per cent of area at	100
5 per cent of area at	50
4 per cent of area at	50
Average	95
(*b*) Topography:	
10 per cent of area at	50
90 per cent of area at	100
Average	95
(*c*) Precipitation, average	75
(*d*) Character of cover:	
90 per cent of area at	75
10 per cent of area at	50
Average	63
(*e*) Forest cover, average, negligible.	

(*f*) Summary of protective value as a whole:[1]

Soil	95
Topography	95
Precipitation	75
Cover	63
Total	328
Average	82

2. FOREST BELT ONLY

(*a*) Soil	100
(*b*) Topography, average	100
(*c*) Precipitation (of small consequence)	75
(*d*) Cover:	
Forest	75
Other	75
(*e*) Forest cover only	100
(*f*) Summary: Average of (*a*), (*b*), (*c*), and (*d*)	86

CRITICAL FOREST AREAS

Confined practically to the approximately 250 square miles of lowland hardwoods occurring as spotted stringers along major water courses. These have negligible effect on run-off of precipitation that falls in them. They serve to ameliorate the effect of the high flood waters in bank saving, changing of channel, and erosion from these areas themselves. Although they do not prevent this in times of exceptional high waters, they serve even then to retard somewhat the speed of the current.

These areas have not generally been cleared, but some clearing for farming has taken place. The State forester of North Dakota expresses an opinion that the solution lies in revetments. But it is believed that it is worth while to give consideration to establish a practice of retaining at least a narrow stringer along the present banks. This can be accomplished through education, since the farmer will be interested in safeguarding his clearings from cutting. Where clearing is in connection with removal of timber products it would be necessary to provide some kind of public ownership; however, it is questionable if the amount of benefit would justify the expenditure of funds for purchase and administration. This is a matter which must be left for further detailed investigation.

RECOMMENDATIONS FOR THE WATERSHED

A. *To be retained on forest for watershed protection.*—About 250 square miles, the pine lands and a major part of river bottom lands amounting to less than 0.5 per cent of the area.

B. *Measures to keep forest land productive.*—

1. Investigations to be made as to the value of erosion control along stream banks.
2. Planting strips either cut off or naturally denuded.
3. Maintain Federal administration of national forest lands.

[1] Forest omitted because already considered under cover.

CRITICAL AREAS OTHER THAN FOREST

These consist of heavy clay soil areas in various degrees of erosion from slight to ultimate in the form of very minutely dissected steep and broken topography, known as Bad Lands. The areas do not always occur in compact bodies in any one place. They are more often situated along the breaks of the main water courses where the stream has cut its way through the more readily erodible formations, exposing them to water and, to a less degree, wind action.

The Bad Lands amount to about 2,300 square miles. Of the clay soil areas it is impracticable to indicate the extent. Only a portion of the clay soil is critical; some of them are so situated that they are under cultivation (with irrigation) and others have favorable topographic factors or beneficial admixtures in the soil. On the whole, the clays are critical where clay soils adjoin the Bad Lands or where the topography is pronounced.

The critical clay-soil areas and the Bad Lands have a cover of herbaceous vegetation varying from very sparse to none at all. In a few localities sparse tree growth (western yellow pine and some juniper) occurs; this is so scattered that it is of little consequence in preventing erosion or run-off.

With the exception of a limited portion, which can practically be used for farm-crop production, the only possible economic utility of these areas in the Bad Lands is grazing. As a general rule, improperly managed and uncontrolled grazing has depreciated materially such beneficial effects on soil binding and retarding of run-off as grasses may have.

Noteworthy among these Bad Lands and badly eroded clay areas are one in the Pierre shale formation in the headwaters of the Moreau or Owl River in South Dakota, a belt from 6 to 30 miles wide on the west side of the Missouri River and extending some 50 miles up the Owl River in South Dakota, and a belt up to 15 miles wide, principally from the Lance formation on the south side of the Missouri River in Montana. It is reported that about 310 square miles along the breaks of the lower Missouri between Camp Creek and Buffalo, S. Dak., have been badly denuded and that considerable sheet and gully erosion has taken place. It is also reported that about 230 square miles around Pedia, S. Dak., are badly denuded and that erosion is quite prevalent. It is also reported that considerable bank erosion is occurring along the banks of the Missouri, Cannon Ball, and Grand Rivers.

RECOMMENDATIONS FOR WATERSHED

Two possible lines of approach toward ameliorating the injurious effects of these areas should be considered.

Where uncontrolled grazing has a material effect the practicability of bringing about control should be investigated. On private lands this may be accomplished either through State or Federal acquisition or through regulatory State laws. The publicly owned lands may perhaps be practically put under some form of control through appropriate congressional action. Among many other difficulties the publicly owned lands and the private-owned lands that might be

acquired are even more scattered than are the critical areas themselves, irrespective of ownership. In spite of these difficulties this first line of approach will probably be found to be more promising than the second.

The other suggesed solution is to plant tree or shrub species on the Bad Lands and on some of the worst of the clay lands, where even without grazing soil-binding grasses will not thrive. Consensus of opinion of foresters who are more or less familiar with the question is against the practicability of such attempts. Climatic, meteoric, and soil conditions are predominantly inimical to tree growth. There is, however, enough possibility to justify special investigation, considering the favorable influence that might result from success in such planting.

MUSSELSHELL RIVER

(Area 48)

LOCATION AND AREA

Located in approximately the center of Montana. The Musselshell River heads in the Little Belt Mountains in southwestern Montana and flows easterly to longitude 108° west, where it turns abruptly and flows north to the Missouri River near the geographic center of the State.

The Yellowstone River drainage lies to the south, the upper Missouri River Valley lies to the north and west.

Area.—Nine thousand six hundred and six square miles, all in Montana.

TOPOGRAPHY

The topography of this unit is not distinctly defined, except in the western end, where it becomes more rugged.

Relative elevations.—The Musselshell River heads at elevation of 7,000 and flows into the Missouri at an elevation of about 2,700 feet; 75 per cent of the area lies between 2,700 and 5,000 and constitutes the broad prairie areas of this watershed; 25 per cent lies between 5,000 and 7,000 feet and consists of the rolling and mountainous portion of the unit.

Slopes.—The slopes are steep in the extreme western portion of the unit lying in the mountains. In the rolling portion they are moderately steep, while in the lower sections they are almost flat. In the flatter sections the slopes are at times relieved by sharp draws in which the slopes are rather steep, but ordinarily these draws are small in extent.

Prevailing exposure.—The prevailing exposure is mostly southeast and some northwest.

Drainage.—The general drainage is to the northeast. The tributaries are relatively short in the upper area, and parallel the general course of the main stream, while in the lower area they enter the main stream about at right angles to its course. Drainage on the whole is fairly distinct.

Velocity of streams.—The velocity of the main stream at low stage is 1 mile per hour, under extreme flood, 3 miles per hour, with a normal flow of 1½ miles per hour.

Character of streams and stream beds.—The main watercourse is a reasonably swift, clear stream at its source in the mountains, and gradually becomes more meandering and sluggish as it approaches its mouth. The upper stream bed is gravelly and sandy; the bed becomes more silty and mucky lower down. Banks are low to moderately high. Low-water channel changes through shifting of material in high-water stages. Tributary streams resemble the main stream.

Water-storage possibilities.—Musselshell Reservoir system contains 324 square miles in Lewis and Clark County, Mont. This area was segregated for storage purposes for irrigation.

Topography classification

	Elevations
Plains, 75 per cent of area	2,700 to 5,000
Rolling land, 20 per cent of area	5,000 to 6,000
Mountainous, 5 per cent of area	6,000 to 7,000

GEOLOGY AND SOILS

A. *Geological formations.*—The Lance formation in the southern part of the area, covering about 690 square miles or 7 per cent of the entire unit, consists largely of shales in the lower part and gives rise to rolling clay hills capped with sandstone. Erosion is prominent. The Lance in the northeastern portion of the unit, approximately 1,200 square miles, is characterized by a similar topography except in the vicinity of the Musselshell River. Here the surface relief is very strong and erosion is very heavy.

The Claggett and Bear Paw formations aggregate 2,381 square miles or 25 per cent. Both give rise to easily erodible soils. Topography, however, is favorable except for a limited area along the Musselshell River in the east part of the unit. Here the ground is more broken.

The Colorado structure covers about 1,571 square miles, or 16 per cent of the unit. It decomposes into a heavy clay. In general the topography is rather subdued. In view, however, of the fact that the formation lies at the higher elevations and that drainage is well developed, erosion is quite rapid.

The rest of the formations within the unit, chiefly Fort Union, Judith River, Eagle, Quadrant, and Ellis, decompose into material not readily erodible.

B. *Soils—Loams.*—Comprises about 5,375 square miles, or 56 per cent of the unit. The soils in this type are prevailingly deep, sandy loams to loams, rather free from gravel. In the mountains the loams usually are shallow and stony. On the plains area the topography is rolling and drainage is well developed. The stream courses are deeply intrenched, particularly in the southeast portion of the unit. Grass cover is fair. Erosion is light.

In the mountains or generally forested belt erosion is light owing to the shallow, stony character of the soil and the fair grass and forest cover. What erosion that does occur is chiefly of the gully type.

Clays.—Cover about 3,423 square miles or 36 per cent. These soils as a rule are deep, plastic clays. The clays between the Snowy Mountains and the Musselshell River, approximately 3,200 square

miles, occupy a broad gently rolling series of depressions. Erosion is chiefly of the sheet character and while fairly active is slight in comparison to the rest of the clay soils in the unit, formed chiefly from the Colorado, Claggett, and Bear Paw structures. In these types the erosion is heavy. Sheet erosion, however, is rather active.

Bad Lands.—This type embraces 808 square miles, or 8 per cent. The principal Bad Land areas are comprised of belts about 6 miles wide along each side of the Musselshell River in the east part of the unit. The type is mostly shales in various stages of deterioration. Erosion is very active. Scattering growth of western yellow pine and juniper occur. Grass cover negligible.

CLIMATE

A. PRECIPITATION

(*a*) *Average precipitation*

	Inches
1. Yearly average	16
2. Theoretically effective flood precipitation:	
(*a*) December–June, inclusive	10
(*b*) December–February, inclusive, virtually all snow	2.5
(*c*) March–April	2
(*d*) May–June, most direct influence on floods	5.5
3. Snowfall converted into equivalent precipitation at time of its melt:	
(*a*) March–April	1.5
(*b*) May–June	1
4. Theoretically effective equivalent precipitation (2) plus (3):	
(*a*) March–April	3.5
(*b*) May–June	6.5

(*b*) *Geographical distribution.*—Two diverse types of precipitation. In the forested mountains and near by, about 30 per cent of the unit, at altitudes generally about 5,000 feet, the annual precipitation averages about 25 inches, about half in the form of snow from November to April. Occasional winter thaws occur but the spring melt is not under way until April and the snow is well gone by June. The run-off from this augments the heavy rainfall of May to July, which averages about 10 inches. Below 5,000 feet, in the natural prairie country of rolling character, the annual precipitation drops to 14 inches, of which about one-third comes as snow. Aside from the occasional "Chinook" thaws from midwinter on, the main spring thaw is over by April. The May and June precipitation runs about 5 inches. In the mountains the precipitation in individual years may go as high as 33 inches, distributed about as the average. In the lower country the highest precipitation in any year may go to 20 inches, the increase occurring mainly in the spring and summer months. The spring snow melt and the heavy May to June precipitation are the cause of the perennial spring and early summer high waters.

B. TEMPERATURE

1. The mean annual temperature of the unit approximates 43° F.
2. The mean growing season temperature approximates 59° F.

The forested mountain temperature has a mean of 40° for the year, with 54° in the growing season, while the rolling country below takes a 44° mean for the year and 62° for the growing season.

HISTORICAL DEVELOPMENT

1. The unit as a whole is used in connection with stock industry and dry farming. Most of the area is naturally prairie, some of which has sparse tree growth along the Musselshell River. A relatively small area in the more mountainous portion of the unit carries rather dense forest cover of high watershed protective utility.

2. The distribution of wild lands of all classes is entirely due to natural factors, primarily climatic and physiographic.

3. The forested belt is in practically its natural state, occupying the same areas as before the advent of civilization.

	Square miles
Total area of prairie land in the Musselshell Basin	8,448
Total area of timbered belt	1,158
Land in the timbered belt further classified as—	
Land in commercial timber	149
Protection forest and scrub growth	834
Total area under forest cover	983
Nonforested lands in timber belt	175
Ownership in timbered belt:	
Private	554
State	9
National forest	592
Other Federal	3
Total	1,158

The area devoid of forest cover within the timber belt is its natural condition. The 175 square miles comprising this class of land are principally grassland, where site conditions are too severe for forest growth and barren land above the timber line.

CONDITION OF LANDS OTHER THAN FOREST

(*a*) *Improved lands.*—The total cultivated area is around 800 square miles. The term "cultivated" includes lands in fallow as well as those actually in crop, but does not include native grass areas from which hay is cut. The tame-hay acreage aggregates 135 square miles, of which 110 miles are in tame grass and legumes and 25 miles are cropped to small grains. The remaining cultivated area, 665 square miles, is cropped chiefly to small grains in the following order of importance based on acreage: Wheat, oats, barley, rye, and flax. Some little corn is produced throughout the unit.

Agriculture is confined mostly to the lighter-textured soils. Very little steeply sloping land is being farmed. Present cultivation methods have little bearing on the erosion problem, particularly in view of the small percentage of the unit that is being farmed. Some erosion trouble, however, is being experienced from wind blowing on clean fallow lands. The only permanent cure for soil blowing is the restoration of fiber to the soil. On lands on which grain production is to be continued soil blowing can be reduced in considerable degree by the use of cultivators that have a clod rather than a fine mulch. Erosion from run-off direct on the cultivated lands is slight.

(*b*) *Unimproved lands.*—The Musselshell unit contains about 8,300 square miles of nonforested and noncultivated lands, used largely as

pasturage. Of this area there are about 600 square miles of publicly owned lands (State and unreserved, unappropriated Federal) and about 7,700 square miles of privately owned land.

Publicly owned lands.—About the time white men began settlement in this region, in about 1880, the excellent grazing conditions was one of the attractive features and at that time the range was well sodded with a large variety of perennial grasses such as buffalo, grama, and wheat grasses, having a density of about 80 per cent of a complete ground cover. This region has experienced a long period of unregulated grazing, overstocking, and continuous use at all seasons of the year, which has reduced the ground cover to about 50 per cent of a complete cover and the sod-binding grasses have given away to a larger percentage of annuals, grasses, and weeds, with light root systems. The rough exposed slopes have suffered much greater than the flat bench lands with resultant increase of wind, sheet, and gully erosion. This condition has increased the siltage carried by the streams of this region by about 30 per cent over that of 50 years ago.

Privately owned lands.—The lands in private ownership have largely reached that status in the past 25 years, much of it was in an overgrazed condition at time of patent and very little has been done to improve conditions so that it is not much better than the public land, probably 10 per cent. It is reported that in the east half of Musselshell County there are probably 800 square miles of private and public lands badly organized and bordering on a critical situation as to erosion and run-off.

Condition of forest.—A considerable part of this timbered belt is chiefly grazing land intermingled with sparse growth. Likewise, a good deal of the area listed as prairie land has scattering tree growth, especially along the slopes of the Musselshell River. The species in the pine type are lodgepone pine, Douglas fir, and western yellow pine. River bottom hardwoods consist of cottonwood, green ash, and box elder and various shrubs. It has not been necessary to remove this growth for farm development. Only a small amount has been removed in the vicinity of the towns. No appreciable cutting away of the river banks has resulted.

A. *Effect of lumbering.*—Logging in this region is confined primarily to mine timber from the private timber holdings in the vicinity of Roundup. Cutting on the national forests is limited to the small demand for farm use in the surrounding thinly populated districts. The cut is far less than the annual growth. Natural reproduction follows logging in the mountainous parts of this basin. There has been no shrinkage of such forested areas through activities of man. In the mixed grazing and timber lands in private ownership it is doubtful if reproduction is replacing the timber as fast as it is removed. Conditions in the grass type are not as favorable for reproduction so the process of regeneration is slow; and unrestricted cutting in the privately owned timber is detrimental to complete restocking. Consequently the mixed timber and grassland type is gradually becoming more and more grassland. Cutting on any of the forested areas does not bring about any appreciable erosion. Grass or natural reproduction follows removal of timber to complete the protective covering.

Protective value of watershed

1. WHOLE UNIT

(*a*) Soil:	
55 per cent at	100
10 per cent at	50
35 per cent at	75
Average	86
(*b*) Topography:	
50 per cent at	75
75 per cent at	100
20 per cent at	75
Average	94
(*c*) Precipitation:	
30 per cent at	75
70 per cent at	100
Average	92
(*d*) Character of cover:	
9,105 square miles at	75
480 square miles at	100
500 square miles at	75
Average	77
(*e*) Forest cover:	
483 square miles at	100
500 square miles at	75
Average	86
Summary of protective value as a whole:[1]	
Soil	86
Topography	94
Precipitation	92
Cover	77
Total	349
Average	87

2. FOREST BELT ONLY

(*a*) Soil	100
(*b*) Topography, average	75
(*c*) Precipitation, average	75
(*d*) Cover:	
Forest, 483, at	100
Other, 675, at	75
Average	85
(*a*) Forest cover only, average	86
Summary, average of (*a*), (*b*), (*c*), and (*d*)	84

[1] Forest omitted because already considered under cover.

CRITICAL FOREST AREAS

About 480 square miles of forested area in the national forests and a few square miles outside can be considered as critical. These now have beneficial effect. Maintenance of the forest cover is assured through national-forest administration.

RECOMMENDATIONS FOR WATERSHED

A. *Area to be retained in forest.*—Same as exists now within national forests.

B. *Measures to keep forest land productive.*—No measures needed to keep forest land productive in addition to what is already being done.

CRITICAL AREAS OTHER THAN FOREST (SUPPLEMENTAL)

These consist of heavy-clay soil areas in various degrees of erosion from slight to ultimate in the form of very minutely dissected steep and broken topography, known as Bad Lands. The areas occur in relatively small bodies scattered throughout the unit and generally are situated along the breaks into the master streams where the water has cut its way through the more highly erodible formations exposing them to water and, to a less degree, wind action.

The Bad Lands amount to about 850 square miles. Of the clay-soil areas it is impracticable to indicate the extent. Not all areas of clay soil are critical; some of them are so situated that they are under cultivation (with irrigation) and others have favorable topographic factors or beneficial admixtures in the soil. On the whole, the clays are critical, where clay soils adjoin Bad Lands or so as the distance from the Bad Lands increases.

The critical clay-soil areas and the Bad Lands have a cover of herbaceous vegetation varying from very sparse to none at all. In a few localities sparse tree growth, yellow pine, occurs; this is so scattered that it is of little consequence in preventing erosion or run-off.

Except for a small portion of the clay-soil lands which could practically be reduced to farm-crop production, the only possible economic utility of these areas fading to negligible in the Bad Lands, is grazing. As a general rule, improperly managed, uncontrolled grazing has depreciated materially such beneficial effect in soil binding and run-off retarding as these grasses may have had.

The outstanding Bad Lands and other heavily eroding clay-soil types are:

The Bad Lands belt, about 12 miles wide, along the Musselshell River in the east portion of the unit.

The intermingled Bad Lands and other clay types along Crooked and Willow Creeks.

RECOMMENDATIONS FOR WATERSHED (SUPPLEMENTAL)

Two possible lines of approach toward ameliorating the injurious effects of these areas should be considered.

Where uncontrolled grazing has a material effect, the practicability of bringing about control should be looked into. It is not possible with the present hurried, incomplete investigation to arrive at definite

conclusions on this point. On private lands this may be accomplished either through State or Federal acquisition or through regulatory State laws. The public-owned lands may perhaps be put under some form of control through appropriate congressional action. Among many other difficulties that are foreseen is that the public-owned lands and the private-owned lands that might be acquired are even more scattered than are the critical areas themselves, irrespective of ownership. In spite of these difficulties this first line of approach will probably be found to be less unpromising than the second.

The other suggested solution is to plant tree or shrub species on the Bad Lands and on some of the worst of the clay lands where even without grazing, soil-binding grasses will not thrive. Consensus of opinion of foresters more or less familiar with the question is against the practicability of such attempts. Climatic, meteoric, and soil conditions are predominately inimical to tree growth. There is, however, enough possibility to justify specific investigation, considering the great favorable influence that might result from success in such planting.

UPPER MISSOURI

(Area 49)

LOCATION AND AREA

The upper Missouri is formed by the junction of the Madison, Gallatin, and Jefferson Rivers in southwestern Montana and flows in a northerly direction to the center of the western portion of the State, then it turns and flows in an easterly direction to a point near the mouth of the Milk River, the eastern limit of this unit.

Marias and Milk Rivers lie to the north, the Three Forks, Musselshell, and Yellowstone Rivers lie to the south, and the lower Missouri to the east.

Area.—Twenty-six thousand eight hundred and twenty-seven square miles lying entirely within the State of Montana.

TOPOGRAPHY

This area ranges from mountains in the upper portion to the rolling and plains area in the lower country.

Relative elevations.—In the upper Missouri drainages, the altitude ranges from 8,000 feet in the southwest to 2,100 feet in the eastern part of the unit near the mouth of Milk River. About 15 per cent of the area lies between 5,000 feet and 8,000 feet and constitutes the mountainous areas which are rough and broken; 55 per cent of the unit lies between 3,000 to 5,000 feet and consists of the rolling benches and terraced flats along the river proper; 30 per cent of the unit lies between 2,000 and 3,000 feet and consists of the lower plains areas in the eastern section of the unit.

Slopes.—The mountains are very steep and rugged, the rolling and terraced benches of the main portion of the unit moderately steep, while in the extreme eastern part the slopes are very light.

Prevailing exposures.—In the upper southern part the exposure is northeast and southwest while the general exposure is northwest and southeast.

Drainage.—The general drainage is eastward, while the main tributaries parallel the general course of the main stream; however, numerous small tributaries enter the main stream at about right angles to its course. On the whole, drainage is well developed, becoming less distinct in the rolling and plains country.

Velocity of streams.—The velocity of the upper Missouri during normal stages is 1 mile per hour, while during flood stages the velocity is 3.5 miles per hour.

Character of streams and stream beds.—The major stream is relatively swift considering its size. The banks range from solid-rock gorge to moderately low caving banks. The stream bed for the most part is gravel and cobblestones. In the gorge sections considerable of the bed is solid rock while in the lower section there is an abundance of sand. There is a minor shifting of low-water channel during high-water stages.

Water-storage possibilities.—On the upper Missouri the storage possibilities have been developed by private interests for power projects, while in the Sun River drainage the United States Reclamation Service has developed the storage sites for irrigation purposes.

Topography classification

	Per cent of area	Elevation
		Feet
Mountains	15	5, 000–8, 000
Rolling land	55	3, 000–5, 000
Plains	30	2, 000–3, 000

GEOLOGY AND SOILS

A. *Geological formations.*—The Bear Paw and Claggett structures, aggregating about 2,141 square miles, or 8 per cent of the unit, mostly were covered by the continental ice sheet. The glaciation over the greater portion of both was either very feeble or has largely eroded away. The surface relief as a rule is strong, the plant growth scant, and the structures break down into heavy clays.

The Colorado, 5,150 square miles, also gives rise to a highly erodible soil. Approximately 3,750 square miles, or 75 per cent, of this formation have a fairly deep covering of glacial drift and glacial lake material. On about 1,400 square miles the drift is very light or entirely lacking.

The foregoing structures are confined almost entirely to the nonforested plains and foothills country. The remaining formations in the plains territory, chiefly Judith River, Eagle, Kootenai, and Montana, give rise to loamy soil material.

In the mountain or generally forested regions the geological structures break down into soils not easily eroded. The principal rocks here are granite, gneiss, schists, quartz, manzonite, volcanics, sandstones, sandy shales, and limestones.

B. *Soils—Loams.*—Loams cover approximately 22,269 square miles, or 83 per cent of the unit.

This type in the plains territory varies from sandy to clay loam on the lower ground to gravelly and stony to silt loams in the upland districts. The loams are fairly deep, on an average, but wide variations are found.

In the mountainous or forested sections the soils are entirely loam. The soil is prevailingly shallow and varies from gravelly to stony. Along the stream courses the soils are deeper and contain less stone and gravel than on the slopes. Local glaciation has had a marked influence on the soils along most of the master streams in the mountain section.

The loam soils in the extreme east portion of the unit, about 4,000 square miles, are characterized by a moderate degree of sheet and gully erosion. In general, on the rest of the loam soils, including the mountainous forested sections, erosion is light, due primarily to the open texture of the soil mass, and the fair grass and forest cover.

Clays.—Clays embrace about 2,022 square miles or 8 per cent of the unit. With little exception this type covers the outcroppings of the Colorado, Claggett, and Bear Paw structures and runs fairly deep. Vegetation as a rule is scanty. Drainage is well defined. Erosion is heavy.

Bad Lands.—Cover around 2,556 square miles, or 9 per cent, of the unit. These include the more rough broken outcrops of the Bear Paw, Claggett, and Judith River structures. Soil is mostly clay and is comparatively shallow. As a result of the strong surface relief, the very scant vegetation and the character of the soil material, erosion is excessive.

CLIMATE

A. PRECIPITATION

(a) Average precipitation

	Inches
1. Yearly average	17.0
2. Theoretically effective flood precipitation:	
(*a*) December–June, inclusive	11.5
(*b*) December–February, inclusive, virtually all snow	3.0
(*c*) March–April	2.0
(*d*) May–June, most direct influence on floods	6.5
3. Snowfall converted into equivalent precipitation at time of its melt:	
(*a*) March–April	1.5
(*b*) May–June	1.5
4. Theoretically effective equivalent precipitation (2) plus (3):	
(*a*) March–April	3.5
(*b*) May–June	8.0

In forested mountain 10 per cent of unit, annual precipitation averages about 20 inches. About 10 inches is snow from November to April, and 6 inches is May to July rain. The snow melt begins in March in the lower mountain country and ordinarily continues into July.

Lower rolling prairie country has annual precipitation under 15 inches. May to July has heavy rainfall of 7 to 8 inches. The winter snowfall is relatively light and has usually melted by mid-April.

The rains of May-July are the principal cause of high-waters augmented by the snow-melt run-off in the mountains which sometimes is very rapid.

In the rolling country annual precipitation may reach about 22 inches; May and June may have from 13 to 14 inches. The mountain precipitation has shown maximum annuals up to 30 inches with about 12 inches in May, June, and July.

B. TEMPERATURE

1. The mean annual temperature of the unit approximates 42° F.
2. The mean growing season temperature approximates 58° F.

The rolling prairie section enjoys a mean annual temperature of 42° while May-July record a mean of 60°. The mountain areas have a mean annual temperature of 41° with a growing season mean of 56°.

HISTORICAL DEVELOPMENT

1. The upper Missouri Basin is principally prairie land. Grazing predominates in the use of this land, although there are some irrigated districts under cultivation and some dry-land farming in the region surrounding Great Falls. The timbered areas lie at the western edge, on the Continental Divide and the Belt and Little Belt Mountains, outposts of the main Rockies.

2. Both forested areas and prairie are confined within their natural boundaries by climatic and physiographic conditions.

3. No changes by encroachment of either the prairie type or timber type are noticeable. No appreciable inroads have been made on the timber type through land clearing for agriculture.

	Square miles
Area in prairie	23, 065
Area in timber belts	3, 762
Further classified as:	
Commercial timber	750
Protection forest and young growth	2, 283
Under forest growth of all kinds	3, 033
Nonforested lands	729
Ownership in timber belt:	
Private	573
State	42
National forests	2, 641
Other Federal lands	506
Total	3, 762

4. Nonforested lands within the timbered belt are principally grasslands where site conditions are too severe for tree establishment and barren areas above timber line.

CONDITION OF LANDS OTHER THAN FOREST

(*a*) *Improved lands.*—The total area under cultivation within this unit is approximately 2,790 square miles, or about 8 per cent of the total area in the unit. This includes land in fallow as well as areas actually in crop, but is exclusive of native grasslands from which hay is harvested. The tame grass and legume hays embrace about 340 square miles. In addition around 75 square miles of small grains are grown for hay purposes. The remaining cultivated area aggregates 2,375 square miles. Small grains, chiefly wheat and oats, make up the greater percentage of this acreage.

For the most part, cultivation is confined to the high plateaus and the more gently sloping plains and foothills sections. A lesser farming territory is comprised of relatively narrow river and creek bottoms. With little exception, cultivation embraces the loam soil type. As a general proposition cultivation has little effect on erosion and run-off. In some places considerable wind erosion occurs on summer fallow land that is dry and fine. Little erosion occurs from run-off direct.

(*b*) *Unimproved lands.*—The upper Missouri unit contains about 29,300 square miles of unimproved lands used largely for pasture. About 3,000 square miles are State and Federal owned lands while about 26,300 square miles are in private ownership. The original cover was largely wheat grasses, fescues, grama, and buffalo, all sod binding. The probable density of this vegetation would average 80 per cent of a complete ground cover. Overstocking at all times of the year and a few misguided attempts at farming have reduced the ground cover materially, and numerous annual plants of less sod-binding proclivities are now present. The density of the ground cover has been reduced to about 40 per cent. The above situation applies to both classes of lands. The area of greatest erosion will be found along the Missouri River from Fort Benton for 200 miles downstream. A considerable area on either side of the river is known as "bad lands," and it is here that considerable siltage is carried into the short water courses draining the area and eventually to the Missouri River.

CONDITION OF FOREST

The forest is all of the pine type, principally lodgepole pine. Western yellow pine occurs in open stands in the vicinity of Helena, and Douglas fir and Engelmann spruce comprise the subalpine type, with limber pine, white bark pine, Alpine larch, and dwarf juniper associating at the altitudinal limits of tree growth.

In places a narrow fringe of cottonwoods and willow borders the river banks. The area of this growth is insignificant. Very little of it has been removed from the banks of streams in clearing land for cultivation. Bank cutting has been observed in this drainage particularly along the Missouri River. The banks covered with hardwood-tree growth are cut as well as the treeless stretches. Thus, it appears that the natural growth along the river courses is not sufficient to hold the banks in high water although undoubtedly it helps.

A. *Effect of lumbering.*—Most of the timbered area of this region is within the national forests, consequently logging is practiced with expectation of preserving the forest cover. Reproduction has followed in the wake of logging. Erosion does not occur on the logged-off areas.

B. *Effect of fire.*—Forest fires in this region are not considered serious. No large acreage has been swept by fire since 1889. The areas burned have been or are in the process of restocking naturally. Erosion has not occurred on the burned areas.

Protective value of watershed

1. WHOLE UNIT

(*a*) Soil:	
85 per cent at	100
5 per cent at	50
10 per cent at	50
Average	92
(*b*) Topography:	
15 per cent at	50
55 per cent at	75
30 per cent at	100
Average	79
(*c*) Precipitation, average	75
(*d*) Character of cover:	
3,033 square miles at	100
28,791 square miles at	75
3,350 square miles at	50
Average	75
(*e*) Forest cover, average	100
(*f*) Summary of protective value as a whole:[1]	
Soil	92
Physiography	79
Precipitation	75
Cover	75
Total	321
Average	80

2. FOREST BELT ONLY

(*a*) Soil	100
(*b*) Topography, average	75
(*c*) Precipitation, average	75
(*d*) Cover:	
Forest, 3,033, average	100
Other, 729, average	75
Average	95
(*e*) Forest cover only, average	100
(*f*) Summary, average of (*a*), (*b*), (*c*), and (*d*)	86

CRITICAL FOREST AREAS

These areas comprise about 3,000 square miles in the forested mountains. All this area is now in good shape. Of this about 90 per cent is in national forest and as well safeguarded from destruction as is reasonable.

The other 300 square miles consist mostly of scattered small parcels lying at or near the boundaries of the existing national forests. While fires are unlikely to happen, there is always that possibility;

[1] Forest omitted because already considered under cover.

it is unlikely that timber utilization will destroy the watershed utility for some time since the areas are rather inaccessible. However, assurance of the continuity of these tracts as protective forest can best be had, through their addition to the national forests of which they are logically parts. A very great proportion of these lands is public domain.

RECOMMENDATIONS FOR WATERSHED

A. *Area to be retained in forest.*—Essentially the present area, 3.033 acres, or about 11.3 per cent of the total area of unit.

B. *Measures to keep forest land productive.*—

1. Continuation of national forests as they stand.
2. Extension of national-forest boundaries to include adjoining integral parts.

CRITICAL AREAS OTHER THAN FOREST (SUPPLEMENTAL)

These consist of heavy clay soil in various degrees of erosion from slight to minutely dissected steep and broken topography, known as Bad Lands. The areas occur in relatively small bodies scattered throughout the unit and are generally situated along the breaks into the master streams where the water has cut its way through the more readily erodible formations exposing them to the action of wind and water.

The Bad Lands amount to about 3,350 square miles. It is impracticable to indicate the extent of the clay soil areas. Not all areas of clay soil are critical; some of them are so situated that they are under cultivation (with irrigation) and others have favorable topographic factors or beneficial mixtures in the soil. On the whole, the clays are critical where clay soils adjoin bad lands or where the topography is pronounced, becoming gradually less and less so as the distance from the Bad Lands increases.

The critical clay soil areas and the Bad Lands have a cover of herbaceous vegetation varying from very sparse to none at all. In a few localities sparse growth of western yellow pine occurs. This is so scattered that it is of little consequence in preventing erosion or run-off.

Except for a small portion of the clay-soil lands which could practicably be reduced to farm-crop production, the only possible economic utility of these areas is grazing. As a general rule, improperly managed, uncontrolled grazing has depreciated any beneficial effect in soil binding and the retarding of run-off that these grasses may have had. The outstanding critical nonforest area is the belt of Bad Lands from 6 to 20 miles wide along the main Missouri, and extending from the east boundary of the unit to about the point of confluence with Arrow River.

RECOMMENDATIONS FOR WATERSHED (SUPPLEMENTAL)

Two possible lines of approach toward ameliorating the injurious effects of these areas should be considered.

Where uncontrolled grazing has a material effect, practicability of bringing about control should be looked into. On private lands this

may be accomplished either through State or Federal acquisition or through regulatory State laws. It may be practicable to put the public-owned lands under some form of control through appropriate congressional action. Among many other difficulties that are foreseen is that the publicly owned lands and the privately owned lands that might be acquired are even more scattered than are the critical areas themselves, irrespective of ownership. In spite of these difficulties this first line of approach will probably be found to be less unpromising than the second.

The other suggested solution is to plant tree or shrub species on the Bad Lands and on some of the worst of the clay lands where, even without grazing soil, binding grasses will not thrive. The concensus of opinion, among foresters more or less familiar with the question, is against the practicability of such attempts. Climatic, meteoric, and soil conditions are predominantly inimical to tree growth. There is, however, enough possibility to justify special investigation, considering the great favorable influence that might result from success in such planting.

BIG HORN

(Area 50)

LOCATION AND AREA

The Big Horn drainage lies in the center of the north half of Wyoming and in the center of the south half of Montana. The course flows northerly from its source in the Big Horn Mountains and into the Yellowstone River, of which it is the largest tributary. The Tongue and Powder Rivers lie to the east of this drainage while the Yellowstone and Snake Rivers lie to the west.

Area:	Square miles
Wyoming	19, 239
Montana	3, 818
Total	23, 057

TOPOGRAPHY

Elevations.—Headwaters country reaches elevation of over 12,000 feet. Elevation at mouth of river is 2,700 feet. The drainage is practically a broad valley surrounded for about two-thirds of its distance from the headwaters by high rugged mountains rising to over 10,000 feet, which comprise about one-third of area. The valley itself is broken by a strip of mountainous country rising to over 8,000 feet about one-fourth of the distance from the main river source. The lower portion of the valley, including nearly one-half of the unit, lies mainly between the 3,000-foot and 6,000-foot elevations, and the upper portion, small in extent, between 5,000 and 7,000 feet. The average elevation of the unit is about 6,000 feet.

Slopes.—The mountainous regions are exceedingly rugged and broken on the whole and contain some of the roughest country in the West. Through a narrow fringe of broken, foothill country, the slopes gradually become more and more gentle until in the lowest valley country the land is almost flat.

Prevailing exposures.—Generally, the aspect is northerly but the heavily broken mountain country is exposed mostly to the northwest and southeast.

Drainage.—The principal tributaries of the Big Horn River are the Wind, Little Wind, and Popo Agie Rivers, which, combined, carry the great perennial discharge. The drainage is quite well established and defined, especially in the forested mountains.

Velocity of streams.—The major water courses are relatively swift for such large streams through most of their length. Two miles per hour is probably an average at normal stages, while at flood stages velocities run to 5 miles per hour and over. In the steep mountain country the streams are much more rapid.

Character of streams and stream beds.—Stream beds of both minor and major streams are gravelly and rocky in general. The major tributaries have moderately low banks, though portions of their flow are through canyons. The streams are quite clear even in times of high waters when they leave the mountains, but through the rolling country they become relatively turbid during heavy flow. On account of climatic conditions the main flow is from the forested mountains. Outside the high-water months of June and July the flow is fairly constant.

Natural reservoirs.—There are no distinctly large lakes which are not already developed. There are many smaller ones, however, the largest of which are on several of the creeks entering the Wind River from the southwest. The mountainous regions on the west have numerous very small lakes.

Water-storage possibilities.—The constructed Shoshone Reservoir has a capacity of 456,000 acre-feet. The Big Horn Canyon project has a capacity of about 300,000 acre-feet. Many other minor possibilities for water storage occur especially in the mountains; prominent among these are those on Paint Rock Creek, Owl Creek, Shell Creek, and Greybull River. It is estimated that none of these will exceed 100,000 acre-feet capacity.

Topographic classification

Mountain (30 per cent of area), elevations of 6,000 to 12,000 feet.
Foothills or terraces (5 per cent of area), about 6,000 feet elevation.
Rolling (55 per cent of area), 4,000 to 6,000 feet elevation.
Plains (10 per cent of area), under 4,000 feet elevation.

GEOLOGY AND SOILS

Geological formations.—The Montana portion of this unit comprises 3,818 square miles, or about 16 per cent of the total area. The Colorado, Lance, Claggett, and Bear Paw structures characterize about 2,800 square miles, or 76 per cent of the Montana area. For the most part these formations give rise to soil material having a high degree of erodibility.

The Wyoming section aggregates 19,239 square miles, or 83 per cent of the total area within the unit. In the Big Horn Basin and the Big Horn Mountains portions, aggregating about 10,300 square miles, the Colorado and the Pierre shale structures comprise about 2,100 square miles. These formations upon deterioration result in highly erodible soils. The remaining 8,200 square miles within the

areas in question give rise for the most part to soils having a moderate degree of erodibility. The Big Horn Mountain range in the forested section is composed of granite. A considerable acreage along the crest of the range is barren rock.

The remainder of the Wyoming portion within this unit is characterized largely by volcanic and other igneous rocks. These give rise chiefly to the loam and clay-loam soil types.

Soils.—Loams aggregate about 17,062 square miles, or 74 per cent of the unit.

In the lowland, or generally nonforested section, the loams usually are comparatively deep typical loams to clay loams in texture. Most of the forested country lies in the mountain region. Here the soils usually are rather shallow and range in texture from loams to sandy loams carrying a considerable quantity of stone.

Erosion in the loam soils is normal but is less severe in the forested country than in the plains sections. Sheet, gully, and bank caving are the principal classes of erosion.

Clays.—Cover approximately 5,995 square miles, or 26 per cent of the unit.

These soils are derived chiefly from the Pierre shale, Colorado, Claggett, Lance, and Bear Paw structures. They are moderately deep, fine textured, and of low water absorption power. Drainage is well developed. Erosion of the sheet and gully types is very active.

Included in the clay area is a considerable percentage of bad lands. The exact area in the bad-land type is unknown. The soil covering in this type is principally clay. Topography is broken to rough and erosion is excessive.

CLIMATE

Average precipitation:	Inches
Yearly average	16.0
Theoretically effective flood precipitation—	
December–June, inclusive	11.5
December–February, inclusive, virtually all snow	3.0
March–April	3.5
May–June, most direct influence on floods	5.0
Snowfall converted into equivalent precipitation at time of its melt—	
March–April	0.5
May–June	2.5
Theoretically effective equivalent precipitation plus equivalent snowfall—	
March–April	4.7
May–June	7.5

Geographical distribution—Three rather diverse types of precipitation.—In the mountains the annual precipitation reaches 20 inches and over at the higher altitudes (about 9,000 feet and up) and about 17 inches average on the whole. Of this about 10 inches occurs in the form of snow in the period October–April. Snow comes at almost any time during the year, but in the summer it soon melts away except at the very highest elevations. The winter snow melts very little until about May, although occasionally some thaws may occur earlier. In May and increasingly in June and July, the melting of the snow gets well under way, and some run-off of melted snow augments the relatively heavy rainfall of May and June which amounts to about 4½ inches. This condition exists over the territory roughly comprising the timber belt.

A rather sharp change occurs in the valley between the mountains at elevations ranging from about 4,000 to 6,000 feet. Here precipitation is light, running 10 inches and under; in the center of the valley away from the mountains, average annual precipitations as low as 6 inches are recorded. About half of this precipitation occurs in the months of May, June, July, and August; and the remainder is about evenly distributed throughout the year. The light winter snowfall has usually melted by the middle of March. This condition applies roughly to the rolling country which contains sagebrush and greasewood.

At the northern end of the drainage, at elevations of 4,000 feet and under, the annual precipitation averages 13 inches. About a third comes as snow from November to March. This snow is frequently subject to severe thaws as early as January, but the final spring break-up and thaw does not get under way until about March and is completed by mid-April. This is the natural prairie region.

Unusual precipitations.—In the mountains the annual precipitation may in individual years be as high as 35 inches.

In the rolling and plains country the precipitation in any month or period or whole year has been recorded at about twice the average, with most of the excess occurring in May to August. Here torrential rains of rather localized character are not uncommon.

Temperature.—The mean annual temperature of the unit approximates 44° F. The mean growing-season temperature approximates 60° F. This fairly represents the temperature in the prairie belt.

In the valley area the average annual temperature is 59° and the growing season mean is 80°.

In the forested mountain belt the mean annual temperature is 40° and the growing-season mean is 54°.

Occurrence of thawing temperatures in each of these types has already been indicated in the discussion of precipitation.

HISTORICAL DEVELOPMENT

This large basin is principally rough prairie land, used to a large extent for the stock industry. Cultivated farms are found along the river, but, as a whole, the thinly populated region has changed the natural condition of the country little. Much of the land throughout the Big Horn drainage is badly eroded waste land, of little or no use to the settlers.

The timbered parts of the drainage lie along the upper edges of the drainage in rugged country. These timberlands are not solidly clad with forest growth, but are broken with large areas of grassy and brushy slopes. The distribution of wild lands is caused principally by climate and physiography.

The natural types of cover still exist within the timbered regions excepting a few comparatively small areas that have been denuded by fires, insects, and clearing in recent years.

The total area in prairie belt is 17,697 square miles; total area in timbered belt, 5,360 square miles.

In the timbered belt, 2,372 square miles are open grazing land and barren areas, leaving only 2,988 square miles under forest cover. Most of the forested area is of the woodland type, having a sparse growth of trees intermingled with grazing land. There are no

figures available to further classify the forest cover, but perhaps no more than 10 per cent, or 300 square miles, is commercial, and the balance, 2,688 square miles, is protective forest.

OWNERSHIP

Very little timberland is outside of Federal ownership. Most of the area in the timber belt lies within national forests. Other Federal timberlands are in Indian reservations.

	Square miles
Private	55
State	31
National forests	4,104
Other Federal lands	1,170
Total	5,360

Most of the treeless areas within the timbered belts are natural openings on which site conditions are too severe for tree growth. About 50 square miles of pure Douglas fir stands on the Shoshone River has been killed by the spruce bud worm. About 20 per cent of the river-bottom hardwoods has been removed in land clearing and for wood products. The acreage involved, however, is small, because this type of tree growth covers only a small area in terms of square miles. The balance of the area in this class is above timber line.

CONDITION OF LANDS OTHER THAN FOREST

Improved lands.—The total area in tillage is about 575 square miles, or 2½ per cent of the total of the unit. This includes lands in fallow and areas actually in cultivated crops. Approximately 270 square miles are cropped to tame hay, of which grasses and legumes comprise all but a negligible acreage. The rest of the cultivated area, 305 square miles, is farmed primarily to grains.

In Wyoming the chief grain crops are oats, wheat, and corn. The area in oats is about three times greater than that for either wheat or corn. The latter two are about equal in acreage.

In Montana wheat represents the greatest acreage, followed by corn and oats in the order given.

Erosion on the cultivated lands is normal. Shoe-string erosion and gullying are the principal types caused by run-off. Some wind erosion is experienced particularly on summer fallow lands.

Unimproved lands.—The Big Horn unit comprises about 17,697 square miles of nonforested and uncultivated lands used largely for pasturage. Of this area there are about 6,000 square miles of public land in State and Federal ownership, the Federal ownership comprising unreserved and unappropriated public domain. There are also about 3,000 square miles of Indian reservations and about 10,300 square miles of privately owned lands.

Originally this area contained a very good ground cover of highly palatable and sod-forming grasses, also considerable areas of sagebrush and grasslands. The grasses consisted of fescues, wheatgrasses, buffalo, and grama grass. In the upper portions of the Big Horn drainage some rather large areas of salt sage existed. The probable density of the original cover was around 70 per cent of a complete

ground cover, while at the present time the ground cover ranges from 10 to 35 per cent of a complete ground cover. This applies to the public and private range.

On the Indian reservation where controlled grazing has been exercised to a considerable extent, the vegetation is not much different from the original conditions. Overgrazing, premature grazing, and the trailing of sheep to and from long-used bed grounds have resulted in reducing the ground cover and erosion has been brought about over a considerable area of the public and private range. This is not true, however, on the Indian Reservation.

CONDITION OF FOREST

The river bottom hardwoods consist principally of cottonwood and willow. Only a narrow fringe of this growth borders the streams and that greatly broken. Practically all of this type is in private ownership. In some parts, notably on Wood River and Shoshone, the banks are being rapidly cut away, including fertile ground in cleared farms. In most cases very little bank cutting has been taking place. The ranchers as a whole are awake to the danger of bank cutting and have taken such measures as keeping the natural growth along the streams intact, encouraging more natural growth, and riprapping to protect the banks.

The timberland away from the main stream courses is all of the pine type. Lodge-pole pine and Douglas fir predominate. Engelmann spruce and limber pine occur above the lodge-pole pine and fir. Some western yellow pine is found along the lower reaches of the river in Wyoming and Montana. Dense stands occur only in scattered patches. Most of the pine type is only sparsely covered.

Effect of lumbering.—Lumbering in this region is confined to a few tie operations and forest products for local use. The timber is too inaccessable for large-scale operations. The areas logged are cut mostly under regulation in order to perpetuate the forest cover.

Effect of fire.—A combination of overgrazing and repeated burning of grass and timber south of the Big Horn National Forest on public domain in the Powder River and Big Horn drainages has resulted in denuded slopes. Here erosion is noticeable. Natural reproduction has restocked the burned areas within the National Forests. No erosion has been reported.

Protective value of watershed

1. WHOLE UNIT

(*a*) Soil:	
30 per cent at	100
45 per cent at	75
25 per cent at	50
Average	76
(*b*) Topography:	
10 per cent at	100
30 per cent at	50
60 per cent at	75
Average	70

(*c*) Precipitation:	
30 per cent at	75
50 per cent at	50
20 per cent at	100
Average	68
(*d*) Character of cover:	
13 per cent at	100
50 per cent at	50
37 per cent at	75
Average	66
(*e*) Forest cover, average	75
(*f*) Summary of protective value as a whole:[1]	
Soil	76
Topography	70
Precipitation	68
Cover	66
Total	280
Average	70

2. FOREST BELT ONLY

(*a*) Soil	100
(*b*) Topography; average	61
56 per cent at	50
44 per cent at	75
(*c*) Precipitation, average	75
(*d*) Cover:	
Forest, 56 per cent at	100
Other, 44 per cent at	75
Average	89
(*e*) Forest cover only, average	100
(*f*) Summary, average of (*a*), (*b*), (*c*), and (*d*)	81

CRITICAL FOREST AREAS

Consists of about 3,000 square miles, almost entirely in the national forests. This area is in good condition from the standpoint of watershed protection and needs no additional attention.

RECOMMENDATIONS FOR THE WATERSHED

A. *Area to be retained in forest.*—In the national forests and in Yellowstone Park—approximately 3,000 square miles, or 13 per cent of the area of the unit.

B. *Measures to keep forest land productive.*—Continuance of existing national-forest and national-park administration and policies.

CRITICAL AREAS OTHER THAN FOREST (SUPPLEMENTAL)

These consist of heavy clay soil areas in various degrees of erosion from slight to ultimate in the form of very minutely dissected steep and broken topography, known as Bad Lands. The areas do not occur in compact bodies in any one place. They are generally

[1] Omitted because already considered under cover.

situated along the breaks of the main water courses where the stream has cut its way through the more readily erodible formations, exposing them to water and to a less degree, wind action.

The Bad Lands extend over an undetermined area. Of the clay-soil areas it is impracticable to indicate the extent. Only a portion of the areas of clay soil is critical; some of them are so situated that they are under cultivation (with irrigation) and others have favorable topographic factors or beneficial admixtures in the soil. On the whole, where clay soils adjoin Bad Lands, or where the topography is pronounced, the clays are critical.

The critical clay-soils areas and the Bad Lands have a cover of a herbaceous vegetation varying from very sparse to none at all. In a few localities, sparse tree growth, western yellow pine, and some dwarf juniper, and lodgepole pine, occurs; this is so scattered that it is of little consequence in preventing erosion or run-off.

The only possible economic utility of these areas in the Bad Lands is grazing. As a general rule improper management and uncontrolled grazing have depreciated any beneficial effect in soil binding and the retarding of run-off that these grasses may have had.

It is reported that 780 square miles of public land on Grey Bull River are badly overgrazed, and that erosion is advancing as overgrazing continues. It is also reported that about 310 square miles of public range on Nowood Creek is badly overgrazed and erosion is becoming critical. The density on this range has been reduced to 10 per cent of a complete ground cover, and Nowood Creek is always muddy, carrying considerable silt at all seasons of the year. It is reported that it has been the practice of stockmen using this range to set fire to the sagebrush and other nonpalatable vegetation with the idea that they would increase the palatable plants. This has brought about a denudation of the ground cover, and erosion is increasing rapidly. Some measures of range control are necessary to remedy this situation.

RECOMMENDATIONS FOR WATERSHED (SUPPLEMENTAL)

Two possible lines of approach toward ameliorating the injurious effects of these areas should be considered.

Where uncontrolled grazing has a material effect practicability of bringing about control should be looked into. It is not possible with the present hurried incomplete investigation to arrive at definite conclusions on this point. On private lands this may be accomplished either through State or Federal acquisition or through regulatory State laws. It may be practicable to put publicly owned lands under some form of control through appropriate congressional action. Among many other difficulties that are foreseen is that the publicly owned lands and the privately owned lands that might be acquired are even more scattered than are the critical areas themselves, irrespective of ownership. In spite of these difficulties this first line of approach will probably be found to be less unpromising than the second.

The other suggested solution is to plant tree or shrub species on the Bad Lands and on some of the worst of the clay lands where, even without grazing, soil binding grasses will not thrive. The concensus of opinion among foresters more or less familiar with the question is

against the practicability of such attempts. Climatic, meteoric, and soil conditions are predominantly inimical to tree growth. There is, however, enough possibility to justify special investigation to consider the great favorable influence that might result from success in such planting.

POWDER RIVER

(Area 51)

LOCATION AND AREA

The Powder River rises in central Wyoming on the eastern slopes of the Absaroka and Big Horn Mountains and flows in a northeasterly direction, entering Montana in the southeast portion and flowing into the Yellowstone River at about latitude 46° 45′ north, longitude 105° 30′ west. This area lies between latitudes 43° and 47° north, longitudes 104° 30′ and 107° 30′ west. To the east are the drainages of Little Missouri and Cheyenne Rivers and to the west the Tongue and Big Horn Rivers.

Area

	Square miles
Wyoming	9, 488
Montana	3, 995
Total	13, 483

TOPOGRAPHY

Elevations.—The Powder River heads at an elevation of 8,000 feet with surrounding peaks above 10,000 feet. The elevation at the mouth is slightly above 2,200 feet. Only a relatively small portion of this unit is below 3,000 feet. About 90 per cent of the area lies between 3,000 and 5,000 feet, which consists of broad expanses of rolling country with about 20 per cent of rather broken topography. Most all of the country above 5,000 feet is mountainous.

Slopes.—In the upper western section of the unit the country is mountainous and the slopes steep. The majority of the unit is rolling with moderate slopes, while in the extreme lower portion the slopes are almost flat.

Drainage.—The general drainage of tributaries and of the main stream is northeasterly to longitude 105° west, where the course changes to about 15° west of north. However, as a whole, the drainage is northeast. The tributaries are comparatively short, and in the lower sections flow in a general parallel course to the main stream. Except in the mountains, the drainage system is not well defined.

Velocity of streams.—The tributaries, entering from the western margin of the unit in the upper section, head among the mountains and are swift streams. The main stream normally flows at the rate of 3 miles per hour, and ranges from 5 miles per hour during flood stage, to almost nothing during extreme dry periods.

Character of streams and stream bed.—In the upper tributaries, the banks of the streams are moderately high and relatively straight.

The stream beds are composed of gravel and cobblestones, the low-water channels of which shift only slightly during freshets. The lower portion of the main stream is winding with low caving banks. The stream bed contains gravel and silt, which shift with each freshet. The lower tributaries partake of the characteristics of the main water course in the locality where they join it.

Water-storage possibilities.—Sudden local downpour of rain, resembling small waterspouts on the tributaries of Powder River, frequently cause a solid wall of water, varying from a few feet to considerable height, to flow down the tributaries, sweeping everything movable before it. This along with the ease with which the soil is eroded makes it almost impossible to maintain storage reservoirs.

Topography classification.—Rolling land, 95 per cent; elevation, 2,200 to 6,000; mountains, 5 per cent; elevation 6,000 to 10,000.

GEOLOGY AND SOILS

A. *Geological formations.*—The Montana portion of this unit aggregates 3,995 square miles, or 30 per cent of the total area. In Montana the Lance and Bear Paw formations cover about 1,700 square miles. These structures, particularly the Bear Paw, result in mostly erodible soil material. The remaining 2,295 square miles in Montana are comprised of Fort Union. This structure here gives rise to loam and sandy-loam soils of good water-absorption power.

About 9,485 square miles, or 70 per cent of the Powder River drainage, lies in Wyoming.

The Big Horn Mountain area, or the generally timbered section, is characterized mainly by granite structures. These, on deterioration, result in soil material of excellent water-absorption power and of a moderate degree of erodibility. The upper limits of the mountain ranges are barren rock.

In the remainder and major portion of the Wyoming section of the Powder River unit, the geological data are very meager. From general knowledge of the locality, it appears that the principal formations are Pierre shales, Colorado, Lance, Kingsbury, Caglameate, and Fort Union, with the Pierre and Colorado structures predominating. The latter two formations, with little exception, give rise to heavy, erodible soils. To a somewhat lesser degree this also is true in the case of the Lance and Kingsbury formations.

B. *Soils.*—Loam comprises about 5,530 square miles, or 41 per cent of the entire unit.

These soils, excepting in the mountain section, are fairly deep and vary in texture from sandy loams to loams, to clay loams. Erosion is normal and is chiefly of the sheet and gully types.

Clays.—Clay comprises approximately 7,950 square miles, or 59 per cent of the unit. The clays uniformly are deep, but vary in texture from sandy to exceedingly heavy. Drainage on the whole is well developed. Surface cover as a rule is scanty. Active sheet and gully erosion occurs. Included with the clays are an appreciable area of bad lands. These are characterized by a rough and very broken topography, and erosion is severe.

CLIMATE

A. Precipitation.—

Average precipitation:	Inches
(*a*) Yearly average	15.0
(*b*) Theoretically effective flood precipitation—	
(1) December–June, inclusive	9.5
(2) December–February, inclusive, virtually all snow	2.0
(3) March–April	3.0
(4) May–June, most direct influence on floods	4.5
(*c*) Snowfall converted into equivalent precipitation at time of its melt—	
(1) March–April	3.0
(2) May–June	0.0
(*d*) Theoretically effective precipitation (*b*) plus (*c*)—	
(1) March–April	6.0
(2) May–June	4.5

Of the 15-inch average annual precipitation about 5 to 6 inches occurs as snow; 4 to 5 inches comes in May and June except in the northern third of the area, where May and June fall is not over 2 inches.

The precipitation may reach two or three times the average excesses occurring, especially in the spring and fall. Much of this comes in torrential rains, local in summer, but rather widespread in spring.

The high-flow stages are caused almost entirely by the rains.

B. *Temperature.*—1. The mean annual temperature approximates 44° F. 2. The mean growing-season temperature approximates 58° F.

HISTORICAL DEVELOPMENT

1. This entire unit is used in connection with the stock industry. Most of the area is a prairie and the small wooded areas are also grazed. The watershed protection given by the forest cover is slight, because of its limited area and sparse growth, therefore run-off is affected far more by the condition of the grazing prairie land than the timbered region.

2. The distribution of wild lands of all classes is due entirely to natural factors, primarily climate and topography.

3. The forested regions in this basin are practically in their natural state. No timbered land has been cleared in the pine type, and very little timber has been removed from the river courses.

	Square miles
Area of prairie belt	12,813
Area of timber belt	667
Nonforested area in timber belt	165
Area under forest cover	502
Ownership of area within timbered belt:	
Private	169
National forests	478
Other Federal lands	20
Total	667

Nonforested lands within the timbered belt are natural openings in the forest cover, that offer conditions too severe for tree establishment.

CONDITION OF LANDS OTHER THAN FOREST

(*a*) *Improved lands.*—The area in cultivation makes up only a very small proportion of the total area within the unit, aggregating but 375 square miles, or less than 2½ per cent. This is exclusive of lands in native grasses from which hay is harvested.

The tame-hay area aggregates about 135 square miles, of which grasses and legumes make up 120 miles and small grains 15 miles. The remaining cultivated area comprising 240 square miles are farmed almost entirely to grains. Wheat is greatest in acreage, corn ranks second, and oats third.

Erosion on the tilled lands is moderate. The principal types of erosion from run-off direct are shoestring and gully. Some little soil blowing occurs, particularly on clean, summer-fallow lands.

(*b*) *Unimproved lands.*—The Powder River unit contains about 12,600 square miles of unforested and uncultivated lands used largely for pasturage. Of this area, about 3,500 square miles are publicly-owned State and Federal, the Federal lands being unreserved and unappropriated public domain. There are also about 9,100 square miles of privately owned lands. Since most of the land is used for pasturage and the greater proportion of private lands is unfenced and used in connection with public lands, there is little or no difference between the two classes of lands as to their present ground cover.

This area originally supported a very good stand of grass and other herbaceous vegetation. A considerable area was covered with sagebrush intermingled with grasses. The grasses consisted largely of wheatgrasses, grama, sedges, and buffalo grass. The probable density at the time of first settlement in this country was around 70 per cent of a complete ground cover. Due to unregulated grazing and to overgrazing the ground cover on these areas has been reduced until at the present time the average density of the ground cover is probably not more than 25 to 30 per cent. In all of the rough Bad Land territory the herbaceous vegetation is very slight, and more or less erosion is present in this type of country. It is reported that about 950 square miles in the Little Powder River in Campbell County, Wyo., is badly overgrazed and a considerable amount of erosion has taken place. More than 1,100 square miles in this region is Government land, and some measures of controlled grazing should be taken to overcome erosion and unsatisfactory watershed conditions.

It is also reported that 505 square miles of public-domain lands south of the Big Horn Mountains on the Big Horn Plateau are very badly overgrazed, and erosion is present throughout the general region. The fact that all of the streams leading out of this territory are loaded with silt indicates that erosion is becoming somewhat serious. Overgrazing throughout this entire unit is quite common, both on private and public lands. Certain portions of public lands are in very bad condition, and the possibilities of reestablishing cover only lie in some method of controlling the grazing on these areas.

FOREST CONDITIONS

All of the timbered area is grazing land intermingled with sparse tree growth. The pine type is principally western yellow pine. Lodge-pole pine occurs at the higher elevations on the Bighorn Forest in Wyoming.

A fringe of hardwoods occur along the major-stream courses. The principal species are cottonwood, box elder, green ash, and various hardwood shrubs. The total area in this form of growth is comparatively little. Only a small amount of clearing has been undertaken along the streams. Washing away of the banks along the Powder River is common. Whether this occurs only along the banks that are bare of hardwood protective covering is not known.

A. *Effect of lumbering.*—Lumbering is intensively carried on in the yellow-pine region. Although the region is thinly populated, the limited supply of timber for fuel, fence posts, and other farm uses is much in demand. Removal of trees by selection cutting is followed by ample reproduction. No erosion occurs on the timbered slopes. The heavy load of silt carried in the Powder River, it is claimed, is from eroded slopes in the prairie type and not the timber type.

B. *Effect of fire.*—Serious damage from fires is uncommon in this region. Natural restocking takes place after fires.

C. No material effect by grazing on forest land.

D. No drainage.

E. General forest conditions are good.

Protective value of watershed

1. WHOLE UNIT

(*a*) Soil:	
40 per cent, at	100
60 per cent, at	50
Average	70
(*b*) Topography:	
95 per cent, at	75
5 per cent, at	50
Average	75
(*c*) Precipitation, average	75
(*d*) Character of cover:	
13,568 square miles, at	50
667 square miles, at	75
Average	70
(*e*) Forest cover, average	75
Summary of protective value as a whole:	
Soil	70
Topography	75
Precipitation	75
Cover	70
Average	72

2. FOREST BELT ONLY

(*a*) Soil	100
(*b*) Topography, average	50
(*c*) Precipitation, average	100
(*d*) Cover:	
Forest, 502, at	75
Other, 165, at	75
Average	75
(*e*) Forest cover only, average	75
Summary, average (*a*), (*b*), (*c*), and (*d*)	81

CRITICAL FOREST AREAS

About 375 square miles of pine type, included entirely in the national forests, exert a beneficial effect on run-off. The condition of these lands is good, being under national forest administration.

The timbered type elsewhere is not considered critical, because the timber is too sparse to have appreciable effect. A possible exception to this is along the major water course, where a few narrow stringer areas of bottomland hardwoods have some influence on bank caving and washing. Inadequacy of data prevents any definite statement in regard to these.

RECOMMENDATIONS FOR THE WATERSHED

Area to be retained in forest.—The national forest area, amounting to about 375 square miles, or about 2.8 per cent of unit.

Measures to keep forest land productive.—Continuance of national forest administration.

CRITICAL AREAS OTHER THAN FOREST (SUPPLEMENTAL)

These consist of heavy clay soil areas in various degrees of erosion, from slight to ultimate, in the form of very minutely dissected steep and broken topography, known as Bad Lands. The areas do not occur in compact bodies in any one place. They are generally situated along the breaks of the main water courses, where the stream has cut its way through the erodible formations, exposing them to water and to a less degree wind action.

The Bad Lands amount to about 15,500 square miles. Of the clay soil areas it is impracticable to indicate the extent. Only a portion of the areas of clay soil are critical; some of them are so situated that they are under cultivation (with irrigation) and others have favorable topographic factors or beneficial admixtures in the soil. On the whole, where clay soils adjoin Bad Lands or where the topography is pronounced the clays are critical.

The critical clay soil areas and the Bad Lands have a cover of a herbacious vegetation, varying from very sparse to none at all. In a few localities sparse tree growth, western yellow pine and some dwarf juniper and lodgepole pine occurs. This is so scattered that it is of little consequence in preventing erosion or run-off.

The only possible economic utility of these areas, fading to negligible in the Bad Lands, is grazing. As a general rule improperly managed, uncontrolled grazing has depreciated materially such beneficial effect in soil binding and run-off retarding as these grasses may have had.

RECOMMENDATIONS FOR WATERSHED (SUPPLEMENTAL)

Two possible lines of approach toward ameliorating the injurious effects of these areas should be considered.

Where uncontrolled grazing has a material effect, practicability of bringing about control should be looked into. It is not possible with the present hurried incomplete investigation to arrive at definite conclusions on this point. On private lands this may be accomplished either through State or Federal acquisition, or through regulatory State laws. It may be practicable to put the publicly owned lands under some form of control through appropriate congressional action. Among many other difficulties that are foreseen is that the publicly owned lands and the privately owned lands that might be acquired are even more scattered than are the critical areas themselves, irrespective of ownership. In spite of these difficulties this first line of approach will probably be found to be less unpromising than the second.

The other suggested solution is to plant tree or shrub species on the bad lands and on some of the worst of the clay lands where, even without grazing, solid binding grasses will not thrive. Consensus of opinion of foresters more or less familiar with the question is against the practicability of such attempts. Climatic, meteoric, and soil conditions are predominantly inimical to tree growth. There is, however, enough possibility to justify special investigation, considering the great favorable influence that might result from success in such planting.

YELLOWSTONE RIVER (DIRECT)

(Area 52)

LOCATION AND AREA

Located in south central Montana, northern Wyoming, and extreme eastern North Dakota, and comprises the Yellowstone River proper and all of its tributaries except Big Horn and Powder Rivers. The Yellowstone River rises in the northwest corner of Wyoming and flows a little north of easterly to join the Missouri River at about the center of the west line of North Dakota.

Area:	Square miles
Montana	27,887
Wyoming	5,024
North Dakota	724
Total	33,635

TOPOGRAPHY

Elevations.—The Yellowstone River proper heads among the Shoshone Mountains in the locality of many peaks over 10,000 feet in

height. The upper catchment basin, including Yellowstone Lake, has a mean elevation of 9,000 feet. At the mouth of the Yellowstone the elevation is a little under 2,000 feet. The rolling lands and plains lie below 5,000 feet, with but a small proportion below 3,000 feet. Scattered through the rolling country are occasional small mountain masses rising 1,500 to 2,000 feet above the general level of the locality.

Slopes.—The upper portion of the drainage basin consists of mountains of the most rugged type. Outside of the mountain area the slopes are mostly gentle, except in "breaks" along the main water courses and in several localities of rather sharply broken topography. The extreme lower portions along the river are almost flat. The flood plain of the Yellowstone is relatively narrow, averaging 5 miles in width. The mountain slopes average 50 per cent or more, with generally narrow valleys between. In the rolling country the slopes average about 15 per cent, and the breaks along the watercourses may go up to 100 per cent.

Prevailing exposures.—The prevailing exposure is generally northwest and southeast, with a minority of east and west in upper headwaters.

Drainage.—The drainage at the headwaters of the main stream and tributaries is northerly, but on the whole, it is northeasterly. No large tributaries come in from the north. Drainage is well defined in the vicinity of the mountains, but toward the lower reaches of the river in the rolling country it becomes less distinct.

Velocity of streams.—At the headwaters among the mountains the streams are rather rapid even in time of normal flow, but after reaching the lower rolling country the water slackens. Streamflow records at Huntly, about halfway down the main river, show a velocity of from 2 to 5 miles per hour; and at Glendive, not far from the mouth, of 1 to 5 miles. Over most of the river flow the velocity at normal averages 1½ miles per hour, at high water, about 5 miles per hour, and at low water, under 1 mile per hour.

Character of streams and stream beds.—From the extreme headwaters the main stream runs for about 100 miles, through rapids, falls, and canyons (except for Yellowstone Lake), and in general, has gravelly or rocky beds and banks. In the open country the banks are steep but moderately low, the stream bed is about 600 feet wide and is sandy or rocky. This portion of the river has bold, sweeping curves, and numerous islands. Between Clark Fork and the mouth of the Big Horn the river is 1,500 to 1,800 feet wide and is free from rapids. The bottom is gravelly and in places the banks are high and steep. Between the Big Horn and the Powder Rivers the width is 2,400 to 2,700 feet, the bottom is of clay and gravel, and the occasional clayey banks are high and steep. Below the Powder River the banks are low and caving, and there are numerous rapids and islands. Through some of its course the flood plain of the Yellowstone is entrenched as much as 200 feet below the surrounding country.

The Tongue River, the only major tributary considered with the Yellowstone unit, closely resembles the lower Yellowstone, only its extreme head being among the mountains.

Starting among the mountains the main streams are rapid and clear with rocky, gravelly water courses. As they enter the plains

country they slacken and become more meandering, the bed becomes less clear-cut and more mucky, and turbidity, especially in high-water periods, increases. As they approach their mouths they are distinctly sluggish, silt-carrying, great plains rivers, subject to extreme variations as to channel width, cutting, and carrying bank materials. This is especially true in high-flow times. All the minor tributaries of either the Yellowstone proper or of the Tongue, have the characteristics of the major water course where they join it.

Swamps.—About 30 square miles, along the Yellowstone River just above Yellowstone Lake, are swamp covered.

Natural reservoirs.—Many small lakes exist at the head of the Yellowstone and in the mountain areas which drain into it. Of these, Yellowstone Lake is by far the largest. Mystic Lake, relatively small, has recently been developed for hydroelectric power.

Water-storage possibilities.—Many minor possibilities occur in places on the mountains. Prominent possibilities along the main river are at Buffalo Rapids, 12 miles below Miles City, Mont., and at Yellowstone Lake.

Classification of topography

	Per cent	Elevation
		Feet
Rolling lands	65	2, 500–5, 000
Mountains	20	5, 000–10, 000
Plains	15	2, 000–2, 500

GEOLOGY AND SOILS

GEOLOGICAL FORMATIONS

Section 1.—East of Billings to north of Yellowstone River and east of Big Horn watershed.

The Fort Union structure, approximately 11,772 square miles, or 35 per cent of the entire unit, gives rise to loams and sandy loam soils. The topography is clearly defined. The principal creeks have cut deep gulches and valleys, and the intervening country is rolling to steep.

The Bear Paw, Claggett, and Colorado formations, about 1,500 square miles, have weathered into a series of gently rolling hills, whose surface cover consists of a thin stand of grass.

The lower structure embraces about 3,364 square miles, or 10 per cent of the unit, and in general gives rise to compact soils. This formation outcrops mostly on rather steep slopes of the master streams.

SOILS

Loam.—Loam comprises about 13,790 square miles, or 41 per cent of the total unit. It is derived primarily from the Fort Union formation and is typically a loam in texture. Occasional sandy phases occur but the acreage is relatively small. The soil, as a rule, is free from gravel and stone. Scoria-capped buttes are prominent features of the southern and eastern parts of the unit. In view of the

generally broken character of the topography, and the thin grass covering, sheet and gully erosion are fairly active. Exceptions occur on the higher benches, notably the mesas on the Ashland division of the Custer National Forest, and on portions of the Tongue River Indian Reservation.

Clay.—Clay aggregates 4,709 square miles, or 14 per cent of the unit.

The soils resulting from the breaking down of the Lance structure are in general rather shallow. In the upper portion of the formation the soil is a sandy clay phase, whereas in the lower part it grades into silty clays to heavy clays.

The soils from the Bear Paw, Claggett, and Colorado to the north of Forsyth are for the most part very heavy clays. They are comparatively shallow, the underlying formations being encountered usually at a depth of 3 to 5 feet.

The clays from the Bear Paw to the north of Billings and on the Cedar Creek anticline are deep, from 8 to 10 feet or more, and are very heavy.

The rolling to broken surface relief in the clay types, the thin grass cover, and the poor water-absorption power of the soil result in heavy erosion. Over the major portion of the clays, gullying is very prominent. In the country north and east of Billings and to the south of Forsyth sheet erosion is the chief type of soil washing.

Considerable bank caving occurs along the Yellowstone and Tongue Rivers.

Bad Lands.—The Bad Lands embrace about 2,018 square miles, or 6 per cent of the area. The soils here are mostly heavy clays with Fort Union sandstones and shales outcropping along the tops of the "breaks." Ground cover is very light to wanting. Slopes are steep and broken. Erosion is taking place at a very rapid rate.

Section 2.—West of Billings and of Big Horn River drainage.

The Bear Paw and Claggett formations occur as a series of clay-covered hills to the north of Columbus and southeast of Billings. These structures are very limited in extent, aggregating only about 336 square miles or 1 per cent of the entire Yellowstone unit.

The Colorado formation, which gives rise to readily erodible soil material, covers about 1,009 square miles, or 3 per cent of the area. Much of it, however, is covered to a considerable depth by glacial and stream deposits.

In the mountain regions proper, or the generally forested belt, the formations are principally igneous. These structures, for the most part, result in loams and sandy loams.

Soils.—Loams: The loams aggregate about 11,773 square miles or 35 per cent of the area.

On the lowland portion the loams prevailingly are of good depth, 5 to 10 feet or greater. The textures grades from typical loams to sandy to silt loams. Considerable rounded gravel and stone occurs well mixed with the soil mass. Along Shields River and between the Yellowstone River and Pryor Mountains, clay loam phase is found. The Shields River area carries little gravel and stone. On the latter area the stone content is small at the lower levels, but increases rapidly as the mountains are approached.

In the mountains or major forest region the soils are comparatively shallow, sandy, and gravelly to stony loams in texture. A considerable average at the higher altitudes is comprised of barren ridges and peaks, carrying little or no soil cover.

Erosion is very moderate over practically all the loam soil type. Soil washing is chiefly of the sheet and gully variety. In the lowland region, by far the greater percentage of the soil is of rather open structure and the grass cover is well established, although the topography is favorable to erosion. On the whole, the flood plains of the master streams are gravelly and stony.

In the mountains the surface relief is very strong. The soil is stony and, excepting on the barren-rock areas, forest cover is well established. Erosion is moderate to light, sheet and gully character.

Clays.—Clays embrace approximately 1,345 square miles, or 4 per cent. The soil material is deep and heavy, and shoestring and gully erosion are fairly active.

CLIMATE

PRECIPITATION

Average precipitation:	Inches
1. Yearly average	16.0
2. Theoretically effective flood precipitation—	
(*a*) December–June, inclusive	11.0
(*b*) December–February, virtually all snow	3.0
(*c*) March–April	2.0
(*d*) May–June, most direct influence on floods	6.0
3. Snowfall converted into equivalent precipitation at time of its melt—	
(*a*) March–April	2.5
(*b*) May–June	1.0
4. Theoretically effective equivalent precipitation (2) plus (3)—	
(*a*) March–April	3.0
(*b*) May–June	8.0

Geographical distribution.—This unit extends into the mountain and the prairie types of climate. In the lower regions precipitation averages 14 inches per year with 7.5 inches coming in May–July. Snow comes from December through February and is usually gone by April. Excessive precipitation is not at all unusual, occurring as local cloud-bursts in the summer, or general regional heavy rains in spring or autumn. It may reach twice the average for the month, but seldom exceeds one and one-half times the annual mean.

The mountain precipitation averages from 20 to 25 inches per year, with more in the high places. Of this about one-fourth comes in May–July. Snow begins melting in April and, with the exception of a number of glaciers and year-long snow banks, is usually gone by late June. Excessive precipitation may occur in any month to more than twice the average for the month, though the annual seldom exceeds one and one-half times the annual mean.

Temperature

	° F.
The mean annual temperature of the unit approximates	43
For higher elevations	39
For lower elevations	46
The mean growing season temperature approximates	58
For higher elevations	52
For lower elevations	62

The contrasts in these temperatures accurately reflects the great differences between the two climates into which this unit extends. The division is one largely of topography, the mountain climate being found at elevations of 5,500 feet and more.

HISTORICAL DEVELOPMENT

1. *Land use and cover type.*—This basin is used chiefly for stock raising. Some dry farming is attempted in the most fertile upland region, and irrigated farms occur along the river course. Most of the Yellowstone Basin is natural prairie, parts of which are wooded with a sparse growth of western yellow pine, but most of which has no tree growth whatever. The eastern end is part of that large area known as the Bad Lands, where tree growth is lacking and even grassy vegetation is scant. The headwaters of the Yellowstone support coniferous forests of high watershed protective utility.

2. The distribution of wild lands of all classes is entirely due to natural factors of climate and topography.

3. The natural types of cover still exist within the timbered regions. Only a relatively small amount of timbered land has been cleared for farming. No other changes have occurred.

Area in prairie belt, 26,568 square miles; area of timbered belt, 7,066 square miles. The timbered belt is further classified as 1,536 square miles of land in commercial timber; 2,700 square miles of protection forest and young growth; 4,236 square miles under forest cover of all kinds; 2,830 square miles nonforested land within forested belt.

Ownership of area within timbered regions: Private, 1,011 square miles; State, 60 square miles; national forests, 4,047 square miles; other Federal land. 1,948 square miles; total, 7,066 square miles.

4. Areas devoid of cover: Excepting a very small aggregate acreage of timberlands cleared for agricultural use, forest cover occupies the ground suitable for forest growth. The nonforested lands within the timbered belt consist of grasslands on dry south slopes and exposed ridge tops where conditions are too severe for tree growth. Much of the barren land is above timber line in the high rugged Absaroka Mountain Range. In this general area spotted along the main watercourses is a strip of hardwoods in the flood plain varying from a narrow stringer to about 4 miles in width. A rough estimate places the area at somewhere between 50 and 100 square miles.

CONDITIONS OF LANDS OTHER THAN FOREST

(*a*) *Improved lands.*—The total area in cultivation within the entire unit is about 2,691 square miles. This includes those areas in crop and also those in fallow; but is exclusive of lands in native grasses from which hay is harvested. About 431 square miles are cropped to tame grass and legume hays. The acreage of small grains that are grown for hay is relatively small, totaling about 49 square miles. Of the remaining 2,211 square miles under cultivation, the small grains, chiefly wheat, oats, and flax, and corn are the principal crops.

In the western portion of the unit hay and the small grains, principally wheat, are the most important crops. In the central part of the

watershed, or from about Columbus to Rosebud, a considerable acreage of sugar beets and corn is grown in addition to the small grains and hay. From Rosebud eastward an increasing proportion of the unit is cropped to corn. Of the total grain acreage in both the central and east portions, corn is exceeded only by wheat.

The total cultivated area aggregates about 8 per cent of the unit. Considering the relatively small proportion of the unit that is being tilled, and further, that cultivation is confined to the soils least subject to erosion on easy topography, the cultivation feature has but little bearing on the erosion and run-off problem. Erosion from run-off direct is slight on the tilled tracts. Wind erosion, however, occurs to some extent over much of the cultivated area, principally on summer fallow land. This situation is being gradually diminished by the increasing application of proper cultivation methods.

(*b*) *Unimproved lands.*—The Yellowstone unit contains 30,000 square miles of unimproved lands used largely for pasturage.

Of this area there are about 2,000 square miles of State and Federal owned lands (unappropriated unreserved lands) the balance, or 28,000 square miles are largely in private ownership.

In its original state this area supported a fine stand of sod-binding, perennial grasses such as wheat, grama, fescues, and buffalo, with an average density of about 75 per cent of a complete ground cover. Little regard has been given to the stocking of these range lands in general, with the result that the average density has been reduced to about 40 per cent and a considerable part of the sod-binding highly palatable plants have disappeared, and have been replaced by less valuable species of the annual types.

It is probable that the grazing capacity of these ranges has been reduced 60 per cent and the siltage has increased 25 to 30 per cent since the seventies, when settlement first began.

The Bad Lands along the Yellowstone River east of Miles City and along the Rosebud River south of Forsyth, Mont., are the areas of greatest erosion. It is reported that about 1,500 square miles in Park County, Wyo., are overgrazed, and various kinds of erosion are in progress. These areas should be more carefully examined to determine the extent and nature of erosion and to find what steps may be taken to eliminate or to reduce it.

CONDITION OF FOREST

The forests at the headwaters of the Yellowstone River are principally protective. Coniferous tree growth begins at an elevation of 5,000 feet, where a narrow fringe of western yellow pine and Douglas fir is found. From 6,000 to 8,000 feet is a wide belt of lodgepole pine which comprises fully 75 per cent of forests in this region below the subalpine zone. The subalpine zone extends to 11,000 feet elevation with Engelmann spruce as the principal species.

From the foothills of this mountainous region to Miles City, and up the Tongue River, occur a number of large areas of open stands of yellow pine. These stands are of woodland type, sufficiently open and intermingled with parks to permit grazing under the forest cover. The condition of these stands has not been changed materially

by settlers. Grazing has not interfered with the timber growth and little or no timberland has been cleared for farming. All of the timber of this region may be considered of the pine type, except a small fringe of hardwoods along the river banks. Hardwood brush does not follow the small stream beds, but is confined to the flood plains of the larger streams. This strip of hardwoods along the Yellowstone widens as the flood plain widens toward its mouth. Then there are long stretches along the banks of the Yellowstone where these hardwoods are entirely absent. This broken distribution is due to nautral causes. Removal of this type of tree growth in clearing for farm lands is insignificant.

Effect of lumbering.—Very little logging is practiced in the entire region. In the mountains the timber is of very little value commercially and very inaccessible. What timber is removed is by regulated cut of the Forest Service. Such removal has not resulted in erosion. Intensive forestry is practiced on the yellow-pine stands within the Custer National Forest located in the Tongue drainage. Utilization is almost complete through the great demand for fuel and fence posts. Cutting, however, is done with care and natural regeneration of the stand results. No erosion has occurred in this timber type.

Effect of fire.—Forest fires are infrequent. The damage occasionally suffered by fires is only temporary; natural reproduction reclaims the site.

Yellow-pine planting has been attempted in this region both by the Forest Service and the Northern Great Plains field station, but with no success whatever. Plantations could not be established in the natural grasslands where natural reproduction failed. Survival resulted only on the rims of the mesa tops where it was later found natural reproduction also became established.

In the rather narrow-spotted hardwood strip along the main watercourse neither logging nor fire has had any significant influence; about the only removal occurs in the vicinity of towns and is insignificant. Opinions vary as to effect on flow and erosion.

PROTECTIVE VALUE OF WATERSHED

	Rating
1. Whole unit:	
(*a*) Soil:	
41 per cent	75
14 per cent	50
6 per cent	50
35 per cent	100
4 per cent	50
Average	78
(*b*) Topography:	
65 per cent	75
20 per cent	50
15 per cent	100
Average	74
(*c*) Precipitation:	
Average	75

	Rating
(*d*) Character of cover:	
4,236 square miles	100
25,918 square miles	75
7,375 square miles	50
Average	73
(*e*) Forest cover:	
Average	75
(*f*) Summary of protective value as a whole:	
Soil	78
Topography	74
Precipitation	75
Cover	73
Average	75
2. Forest belt only:	
(*a*) Soil	100
(*b*) Topography (average)	75
(*c*) Precipitation (average)	75
(*d*) Cover:	
Forest (4,236 square miles)	100
Other (2,830 square miles)	75
Average	90
(*e*) Forest cover only:	
Average	100
(*f*) Summary:	
Average of (*a*), (*b*), (*c*), and (*d*)	85

CRITICAL FOREST AREAS

Approximately 3,000 square miles in the pine type lies practically entirely within national forests. These areas are in good shape; their influence is entirely in the form of conserving run-off. It is probable that erosion would not be serious if these forests were gone, since the annual grass growth would cover the area, but their water retentive capacity and their value in prolonging snow melt would be lost.

Under national forest administration these areas are being improved and their benefits conserved. Little more needs to be done except to round out the national forest areas by the addition of a number of small scattered parcels of critical forest character, most of which are public domain.

Approximately 75 square miles in scattered stringers spotted along the major watercourses are considered critical areas. These are of the lowland hardwood type and almost entirely in public ownership. Some cutting has taken place, especially in the vicinity of denser settlements and towns. The beneficial effect of these areas on run-off is very small, being limited to the little moisture retention action they exert, and to the probable slowing of the speed of high waters in flood periods. Their chief influence is in retarding bank caving and quantity and degree of river channel change. These injuries are now taking place on tracts that are still normally wooded, but the timber stands help ameliorate their effects.

The remaining forested areas are not considered critical. Their influence on erosion and run-off is now neutral; and even if the forests were removed, the areas would not have a detrimental effect, since grass cover would merely occupy more of the ground than at present. The probability of these forested lands losing their timber stands is not great in any case.

RECOMMENDATIONS FOR WATERSHED

AREA TO BE RETAINED IN FOREST

1. Critical areas in national forests adjoining—3,000 square miles.
2. About 75 square miles of timbered bottom land. Total, about 9.1 per cent of unit.

MEASURES NECESSARY TO KEEP FOREST LAND PRODUCTIVE

1. On pine type all necessary is now being done.
2. On lowland hardwood type, better analysis of situation in detail than has been possible heretofore to determine.
    (1) Proper methods of cutting.
    (2) Need of planting.
    (3) At least leaving a strip of timber along stream bank.

Ways and means for accomplishment will likely include Federal or State acquisition.

OPINIONS OF EXPERTS

The opinion of the State forester of North Dakota in regard to similar lands is somewhat at variance to the above. In a letter to the Forest Service he states:

> The Missouri River bottom land forests are often cleared for their rich farming value. As they are flat, the erosion is practically nothing unless the Missouri changes its course and cuts into the land. The forests are then cut away also. Revetment work is the only thing that can protect such land. and that is being done.

CRITICAL AREAS OTHER THAN FORESTS (SUPPLEMENTAL)

These consist of heavy clay soil areas in various degrees of erosion from slight to ultimate in the form of very minutely dissected steep and broken topography—known as Bad Lands. The areas are generally situated along the breaks of the main watercourses where the stream has cut its way through the more readily erodible formations exposing them to water and, to a less degree, wind action.

The Bad Lands amount to about 2,075 square miles. It is impracticable to indicate the extent of the clay-soil areas. Not all areas of clay soil are critical; some of them are so situated that they are under cultivation (with irrigation) and others have favorable topographic factors of beneficial admixtures in the soil. On the whole, where clay soils adjoin Bad Lands or where the topography is pronounced the clays are critical.

The critical clay-soil areas and the Bad Lands have a cover of herbaceous vegetation varying from very sparse to none at all. In a few localities sparse tree growth, mostly western yellow pine, occurs;

this is so scattered that it is of little consequence in preventing erosion or run-off.

Except for a small portion of the clay lands which could practically be reduced to farm-crop production, the only possible economic utility of these areas, fading to negligible in the Bad Lands, is grazing. As a very general rule, improperly managed, uncontrolled grazing has depreciated materially such beneficial effect in soil binding and run-off retarding as these grasses may have had.

Notworthy among the Bad Lands and badly eroding heavy clay areas are a belt of Bad Lands, mostly from the Lance formation and the lower part of the Fort Union from 5 to 10 miles along either side of the Yellowstone River from the mouth approximately to Billings, and practically all the heavy-clay areas, especially in the territory east of Billings.

RECOMMENDATIONS FOR WATERSHED (SUPPLEMENTAL)

Two possible lines of endeavor toward ameliorating the injurious effects of these areas should be considered.

Where uncontrolled grazing has a material effect, practicability of bringing about control should be looked into. It is not possible with the present hurried incomplete investigation to arrive at definite conclusions on this point. On private lands this may be accomplished either through State or Federal acquisition or through regulatory State laws. It may perhaps be practicable to put the public-owned lands under some form of control through appropriate congressional action. Among many other difficulties that are foreseen is that the public-owned lands and the private-owned lands which might be acquired are even more scattered than are the critical areas themselves, irrespective of ownership. In spite of these difficulties this first line of approach will probably be found to be less unpromising than the second.

The other suggested solution is to plant tree or shrub species on the Bad Lands and on some of the worst of the clay lands where, even without grazing, soil-binding grasses will not thrive. Consensus of opinion of foresters more or less familiar with the question is against the practicability of such attempts. Climatic, meteoric, and soil conditions are predominantly inimical to tree growth. There is, however, enough possibility to justify special investigation, considering the great favorable influence that might result from success in such planting.

CHEYENNE RIVER

(Area 53)

LOCATION AND AREA

The Cheyenne heads in Wyoming, flows east, and elbows its course around the southern end of the Black Hills, thence turns sharply northeastward and enters the Missouri just north of Fort Bennett. The other important branch—the Belle Fourche—also originates in Wyoming but runs to the north of the hills and flows into the Cheyenne in eastern Meade County about 50 miles east of the Black Hills. Numerous small streams originating in the Black Hills run directly into the Cheyenne and the Belle Fourche.

TOPOGRAPHY

The western end of the course of the Cheyenne River is through the rugged Black Hills region. The Black Hills rise as high as 4,000 feet above the surrounding plains; Harney Peak, with an elevation of 7,240 feet, being the highest point. There are numerous narrow valleys and deep canyons each containing a swift mountain stream. Practically all of the water has been filed upon. The Homestake Mining Co. uses considerable water for power, mining, and domestic uses. A large amount of water from the north end of the hills goes into the Belle Fourche Reservoir for use in irrigating land on the project of the same name.

About 11 per cent of the 25,510 square miles within the Cheyenne drainage is in mountains (referred to in this report as Hills or Black Hills), 32 per cent each in hilly and in rolling lands and 25 per cent in plains. The head waters (except streams in the Black Hills) rise at an altitude of about 5,000 feet above sea level; the altitude at Pierre on the Missouri, 40 miles below the mouth of the Cheyenne, is 1,457 feet.

The velocity of the Cheyenne River at Hot Springs varies according to flood stages. In low water (January 16, 1919) it equaled about 1½ feet per second. During the flood of May, 1920, it reached nearly 16 feet per second. Ordinarily the stream is sluggish but it is also flashy, showing quick response to precipitation.

The stream is not favorable to the construction of water-storage works and has no natural reservoirs of any consequence, except in the vicinity of Belle Fourche on the tributary of the same name.

Stream records for this river are not very complete except in the upper courses. The lowest station on record is Wasta, on the Cheyenne, a few miles above the mouth of the Belle Fourche, where observations were made during 1915. The following table shows the behavior of the river at that point:

Discharge measurements of Cheyenne River near Wasta, S. Dak.,[1] during year ending September 20, 1915

Date	Gauge height	Discharge	Date	Gauge height	Discharge	Date	Gauge height	Discharge
	Feet	*Second-feet*		*Feet*	*Second-feet*		*Feet*	*Second-feet*
Mar. 31	4.60	532	June 5	5.86	1,020	June 14	6.00	6,880
Apr. 4	5.15	3,170	June 13	11.95	31,700	June 26	3.27	1,860
May 1	2.89	724	June 14	6.95	10,900			

[1] Surface Water Supply of the United States, 1915, Pt. VI, Missouri River Basin, p. 180.

Permits amounting to 484.62 second-feet from Cheyenne River and tributaries between Cascade Springs and Wasta for irrigation, and 1,277 second-feet from tributaries have been granted. Below Wasta permits have been granted for diversion of 207 second-feet for irrigation from Cheyenne River and tributaries.[1]

Total run-off for June was 449,000 acre-feet (7,550 second-feet, mean). For November, 1914, it was 9,280 acre-feet (156 second-feet, mean).

[1] Surface Water Supply of the United States, 1915, Pt. VI., Missouri River Basin, p. 180.

Discharge measurements for the Belle Fourche River at Belle Fourche on the same dates shown for the Cheyenne River in the preceding are shown below:

Date [1]	Gauge height	Discharge	Date	Gauge height	Discharge	Date	Gauge height	Discharge
	Feet	*Second-feet*		*Feet*	*Second-feet*		*Feet*	*Second-feet*
Mar. 31	----------	250	June 5	----------	1,900	June 14	----------	2,260
Apr. 4	----------	760	June 13	----------	4,240	June 26	----------	----------
May 1	----------	775	June 14	----------	2,191			

[1] Surface Water Supply, 1915, Pt. VI, Missouri River Basin, p. 180.

The maximum occurred on April 7, 7,220 second-feet.

The total run-off for June was 94,000 acre feet (1,580 second-feet, mean). For November it was 15,900 acre feet (266 second-feet, mean).

Drainage area above this station is 4,270 square miles. The area above Wasta on the Cheyenne is somewhat more than this, although no data are available.

In that part of the drainage area in Wyoming there were, prior to June 1, 1914, adjudicated diversions of 25 second-feet from Belle Fourche River, and 237 second-feet from tributaries. In South Dakota there are authorized diversions of 102 second-feet from Belle Fourche River above the gaging station and approximately 2,500 second-feet from tributaries. Below the station there are authorized diversions of 3,102 second-feet from Belle Fourche River.

GEOLOGY AND SOILS

Throughout the report, the Black Hills and the plains portions of the watershed will be considered separately. The respective areas of these portions are:

	Square miles
Black Hills	2,755
Plains	22,755
Total	25,510

A. *Geology.*—The Black Hills portion of the Cheyenne drainage is the most important from the watershed protection viewpoint, because of the forest cover and the large number of streams that originate there. The Hills consist of a dome-shaped uplift which has been carved and deeply eroded, the character of the surface having been determined to a large extent by differences in the hardness or erosivity of the rocks, of which there is a great variety.

The characteristic formation of the Hills consists of a series of concentric zones, each marking an exposed geological layer sloping away from the center of the uplift in the vicinity of Terry Peak in the northern part.

The outer portions of the Hills consist of a hogback rim formed by the Dakota sandstone. This formation dips outward and downward and this gives a more or less steep slope toward the plains.

Inside of this are the Spearfish Gypsiferous Red Beds 2 miles or so wide and largely cultivated. The altitude of this zone is about

800 to 1,000 feet lower than the crest of the surrounding hogbacks (highest 4,500 feet).

"The 'limestone country' zone, varying in width from 2 to 15 miles and averaging nearly 6,000 feet in elevation, forms a sort of plateau into which canyons are cut." [1]

Next inside this zone is "the more open park area developed on the schist, slate, and igneous rock. It has many broad valleys lower than the limestone plateau but includes the higher peaks such as Harney, Terry, and Custer. There is a good deal of cultivated land in the broader valleys." [1]

The only other topography in this drainage which justified special mention is the Bad Lands, which occur along the southeast side of the upper Cheyenne Valley between Cedar Creek and Sage Creek. This is badly eroded land characterized by steep, barren cliffs, breaking from the older plateau surfaces to the newer valleys and basins. It is exceedingly rough, although there is no great range of altitude. The clay and silt deposits of this section are very easily eroded. (See also Bad Lands, White River.)

B. *Soils.*—In Wyoming, Crook County, through which the Belle Fourche River runs, may be divided as follows regarding soil:

	Per cent of area
Gumbo	[2] 50
Red clay	30
Porphyry	20
	100

On the plains areas the soils are generally light brown loams and fine sandy loams and fairly deep, with gravel along the streams only.[3]

This description is of the Platte drainage which adjoins the Cheyenne on the south in Wyoming, but applies roughly to the Cheyenne as well.

In South Dakota, where there is more reliable information on soils, there are four types shown on the Cheyenne drainage:

1. The Black Hills, where a large part of the area is very rough and stony. Most of the soil is some grade of loam.
2. Clay, chiefly Pierre series, in the upper valley along the south and east side of the upper course of the Cheyenne above Cedar Creek, on the northeast side of the Belle Fourche above East Elm Creek, and again on both sides of the lower Cheyenne Valley in Armstrong and Stanley Counties.
3. Loam, chiefly of the Morton and Pierre series, between the Belle Fourche River and the Black Hills, extending for 15 or 20 miles along the south side of the Cheyenne below the mouth of the Belle Fourche; again on the north side of the Belle Fourche and Cheyenne from about 25 miles above the mouth of the former to about 25 miles below.
4. Bad Lands, eroded chiefly out of Rosebud silt loam. The soils now exposed are largely clays with varying degrees of silt and sand mixtures. These are located along the southeast side of the river between Cedar and Sage Creeks, extending across the divide into

[1] Visher, S. S.: Geography of South Dakota, University of South Dakota.
[2] Questionnaire submitted by supervisor of the Black Hills National Forest.
[3] Dunnwald, T. J., assistant in soils, University of Wyoming.

White River where they are chiefly located. (See also Bad Lands, White River.)

All of the soils in this drainage are susceptible to erosion above the average. In the Black Hills slopes in general are steep, although the soil composition is better on the whole than that in the plains section of the drainage. The clays and loams of the more level portion of the valley are erodible, due chiefly to their composition.

The Morton loam "extends to an average depth of 8 inches and is underlain by a yellowish or brownish silty clay loam subsoil."[4] In valley bottoms it may be much deeper. Throughout this type, except in transition belts between this and clay, the percentage of silt is high.

The clay, mostly of the Pierre series, is described as follows:

> The most distinguishing characteristic * * * is their sticky nature, which has given them the local name of "gumbo." The soil varies considerably in texture as well as in color, but this sticky nature is a constant feature. In texture the material ranges from a silty clay loam through a silty clay to a heavy clay. * * *
>
> The subsoil, which is encountered frequently at a depth of 6 to 10 inches is a silty clay. * * * Soft shale is usually encountered at 3 to 6 feet below the surface and on some of the badly eroded areas comes to the surface.
>
> A very characteristic feature throughout the area of Pierre clay is the cracking of the soil upon drying. * * * In some instances these extend to a depth of several feet. The tendency to crack * * * is a valuable property. * * * It also permits the rains to enter much more easily.[4]

The Bad Lands are a product of erosion in unusually susceptible soils, chiefly silt loams and clay. With the surface broken erosion continues active in the silty clay thus exposed.

CLIMATE

Precipitation in both hills and plains occurs chiefly during the spring and early summer months. Over 50 per cent of it occurs during April–July. May is the peak month in the plains, 2.89 inches average, and June is the peak month in the Hills, by a very narrow margin over May—2.99 inches average. The average annual for the Hills is 20.24 and for the plains 16.24.

Snowfall in the Hills is 71.7 inches (average annual, seven stations); in the plains, 38.7 inches (average annual, five stations). In the plains over half of it falls between January and March with a heavy fall in April, indicating rapid melting. The mean temperature rises above 32° the latter part of February favoring melting well in advance of the heavy rainfall of May. A little less than half the snow in the Hills falls between January and March with a very heavy fall in April. Here the mean temperature rises above 32° about March, 7 to 10 days later than the plains. Snow melting over most of this area soon follows this late accumulation and is out of the way before the heavy rains of May and June.

All of these factors are exceedingly variable. For example, the precipitation record for May for 15 years at Hermosa on the eastern edge of the Hills shows a range between 0.44 inch (minimum) and 7.15 inches (maximum). The wind velocity (average hourly) at Rapid City in nearly the same location is 8.2 miles per hour; maxi-

[4] Reconnaissance Survey of South Dakota. U. S. Bureau of Soils.

mum is 66 miles per hour. Prevailing wind direction during the spring months of flood danger is west and northwest.

HISTORICAL DEVELOPMENT

In the plains section of this drainage settlement was comparatively late, except immediately around the Black Hills, amounting to very little before 1890. Even yet it is scattered. Urban population is very small and industry undeveloped. Ranching is the principal land use and is still on a pretty extensive basis.

Armstrong and the northern part of Haakon Counties make up the Cheyenne River Indian Reservation, which is still partly under Government administration.

In the plains section over half the land is in farms—54.5 per cent. However, only about one-tenth of this, or 6 per cent of the whole, is cropped and nearly half of this is in hay, leaving only 3.1 per cent of the whole watershed cultivated; 1.3 per cent of the area is in woodland. The Bad Lands shown on the soil map which accompanies the reconnaissance survey of South Dakota cover approximately 7 townships, or 250 square miles, or 1.1 per cent of the total. There is a total of 1,050 square miles, then, which is devoid of cover.

In the Black Hills section of this drainage only 39 per cent of the land is in farms. Less than one-sixth of this, or 6 per cent of the whole, is in crops, and over half, or 3.1 per cent of the entire area, is in hay, leaving only about 3 per cent of the whole area cultivated. Three and nine-tenths per cent of the Hills section of the watershed is in farm woodlands. About 60 per cent of the area classified broadly as the Hills section is in timber, practically all of which is Government owned except 60,000 acres in the Custer State Park. Of the Government-owned land, practically all is devoted to national-forest use.

Development in the Black Hills has been chiefly for lumbering and mining. The lumbering is nearly all carried on under the regulations of the United States Forest Service and accordingly does not affect the forest cover to an extent to involve danger from erosion. Mining activities are now pretty well concentrated in the vicinity of Lead in the North Hills and Keystone in the east central portion and are not now having any serious effect on erosion.

CONDITION OF LANDS OTHER THAN FOREST

(*a*) *Improved lands.*—Fifty-four and five-tenths per cent of the plains portion (22,755 square miles) of the watershed, or 12,400 square miles, is in farm land. Of this 1,365 square miles, or 6 per cent of the whole, is in crops, of which over half is hay. Two hundred and forty-three square miles, or slightly over 1 per cent of the whole plains portion of the watershed, is in small grains, and about 216 square miles, or less than 1 per cent, is in corn, beets, and potatoes.

In the Black Hills (2,755 square miles) 39 per cent of the land, or 1,074 square miles, are in farms. Of the crop area of the hills (164 square miles) 23 square miles, or less than 1 per cent of the whole, is in corn, beets, and potatoes; and 24 square miles are in small grains; 85 square miles, or 3.1 per cent of the entire Black Hills, are in hay.

(*b*) The unimproved land of the plains is almost entirely open-grazing land; a small percentage of it woodland. According to information supplied in questionnaires by the supervisors of the Black Hills and Harney National Forests this land is not over-grazed, except in very small scattered spots, and erosion is not an important consideration. This condition is due to the slump in livestock during recent years and may change with any marked change in livestock economic conditions. Most of this land is fairly level. The effect of fire is not important.

In the hills very careful fire protection is given to the land by the local settlers in cooperation with the United States Forest Service, and this factor is eliminated to the extent that this protection meets with success. Only one or two serious fires have occurred in recent years. Grazing is regulated for forest and range protection more carefully than would be necessary merely to prevent erosion. Other land uses are chiefly lumbering and recreational enterprises.

CONDITION OF FOREST

The important forest area of this region is in the Black Hills. It is all western yellow pine, is nearly all in Government ownership, and dedicated to use as National Forests. It has been so owned and managed for 30 years. The cover has been preserved and protected so as to best serve the aims of watershed protection.

According to information supplied by the forest supervisors the timberland in the plains has not been cleared to any great extent—not more than 10 to 15 per cent, and that for farming. The present area in this type is 1.3 per cent of the whole (plains) and is chiefly along the stream bottoms. This type is made up chiefly of hardwoods, largely cottonwood, ash, elm, hackberry, and box elder. Lumbering, fire, grazing, and drainage have hardly touched it.

PROTECTION VALUE OF WATERSHED

(*a*) *Soil.*—

	Per cent of area	Square miles	Rating
Clay	47	11, 990	50
Loam	41	10, 459	75
Black Hills	11	2, 806	75
Bad Lands	1	255	50
Total	100	25, 510	
Weighted average			63

(*b*) *Topography.*—

1. The range in altitude helps to spread the period of maximum precipitation and snow melting. The surface is not excessively steep except in the hills where there is a good cover of forest and grass.
2. Natural swamps, overflow land, and retention basins are lacking in any important extent, except along the Belle Fourche River.
3. There is no prevailing exposure, due to tortuous courses of rivers along which the valley lies, 75.

(*c*) *Precipitation.*—

1. Light precipitation.

2. Peak is separated from snow melting peak.

3. Precipitation erratic and run-off responsive but not often in large enough amounts to affect general flood conditions.

(*d*) *Cover.*—

	Per cent of area	Square miles	Rating
Grass land	82	20,918	75
Hay	4	1,021	100
Small grains	2	510	75
Corn, beets, and potatoes	1	255	50
Forest	11	2,806	100
Total	100	25,510	
Weighted average			79

CRITICAL FOREST AREAS

The Black Hills constitute a critical forest area. At present their chief uses are timber production, grazing, and recreation. All three are carefully regulated. The present acquisition program of the Forest Service will round out the areas now under Federal control. The only large area here which is not under such control is the Custer State Park, carefully managed and protected by the State for recreational purposes. There is a movement here among private owners to change ranch land to resorts which will increase the watershed protection of such land by the maintaining of continuous cover and the building of artificial lakes.

RECOMMENDATIONS

A study of the Cheyenne River and its watershed does not show any very direct relation between conditions here and the Mississippi floods, or even the Missouri, except possibly erosion in the Bad Lands. However, it is one of many small contributing streams, the effect of which may accordingly be multiplied many times in the case of uniform climatic conditions favoring floods extending over a wide territory. With this understanding, the following recommendations are made primarily as an effort toward assuring a margin of safety in connection with floods in the larger streams; secondarily for their value in local-watershed protection:

(A) 1. The entire Black Hills region now forest land should be retained as such.

2. Further agricultural settlement on land of marginal or submarginal character should be discouraged here—in fact, throughout the watershed. On the national-forest areas this can be accomplished by discontinuing the listing of such land.

3. Interest should be stirred up by forestry-extension work in the maintaining of timber and woodlands on ranches along streams.

The forest area for the watershed should be maintained at its present size or about 2,786 square miles (11 per cent).

(B) 1. Fire protection under the leadership of the United States Forest Service and the State of South Dakota is adequate for the hills region.

2. Careful watch should be kept for insect infestations, especially in the park where there is no cutting and the overmature timber encourages insects.

3. Proper cutting methods are in force on national-forest land in the hills, and this constitutes the greater part by far of the timbered area. They should be encouraged on all private lands.

4. Some planting is considered in the hills, but in general is not urgently necessary. Planting should be encouraged on ranches, both hardwoods along streams and mixed species in windbreaks.

5. Grazing management in the hills is particularly designed to favor forest growth. On the Indian lands in the plains some regulation through the Indian agencies might be put into effect.

6. Legislation should be enacted to convey title only to mineral in mining claims in the national forests, reserving surface rights to the Government to prevent forest devastation on timberlands.

The State of South Dakota has taken no steps toward availing itself of the opportunity offered by section 4 of the Clarke-McNary law for cooperative distribution of forest-planting stock. This should be done if the above recommendations are to be put into effect. First, an extension forester should be appointed; and, second, financial provision for such distribution should be made.

JAMES RIVER

(Area 54)

LOCATION AND AREA

The James River rises in the east central part of North Dakota, flows east for 50 miles. then flows south or a little east of south to its junction with the Missouri, near Yankton. Its drainage area is 360 miles long. north and south; its mouth is 75 miles east of its turn to the south, or 125 miles east of its origin. Its greatest width is 100 miles. It lies between the forty-third and forty-eighth parallels and the ninety-seventh and one-hundredth meridians. It includes approximately 21,715 square miles. The low, flat, poorly drained divides both to the east and west make it impossible to determine exactly its boundary.

The Sioux and the Red Rivers are to the east and the Missouri to the west.

TOPOGRAPHY

"In general the surface is very even, none of it being too rough or too steep for plowing, except in the immediate vicinity of the larger streams and in a few ravines which are cut in its steeper slopes."[1] This statement on the lower James River Valley applies very well to the entire drainage. The total range of altitude is only 850 feet. The James River flows through a trough 50 to 100 feet deep and a half mile or more in width. The only steep land is along the border of this trough and along a somewhat similar break where the upland prairie approaches the Missouri Plateau on the west.

The level of the prairie is also broken by moraines. These are here nothing more than low broad swells some 30 to 50 feet in height, with occasional mounds 15 to 25 feet high. In addition, there are a number of old stream channels 40 to 80 feet below the general sur-

[1] Water Supply and Irrigation Paper No. 90, U. S. Geological Survey.

face of the country. These channels were formed during the glacial period, but are now dry.

The divides both east and west are low, flat, and poorly drained. Some of the larger depressions contain year-long lakes, but most are dry, except during wet periods. One-third of the area has no marked surface drainage and relatively little of the rainfall reaches the streams direct.

The James is a small, sluggish stream which meanders its way slowly through the bottom of its ravine. Its fall averages less than 1 foot to the mile, and for the last 200 miles it is scarcely more than 6 inches. During wet periods its low flood plain is overflowed, but little damage is done. Few of its branches are perennial. Most of them are dry or are marked by pools in the depressions along their beds. Between these pools the water seeps through the gravel, so that they are kept fresh.

There are no good sites for reservoirs. None of the natural depressions drains a large enough area to collect a volume of water. The combined effect, however, of all the small depressions is that of a very large reservoir. The stream beds do not afford a suitable base for heavy engineering works and the glacial soil is such that there would be leakage.

GEOLOGY AND SOIL

Geology.—The lowest formation exposed is the Sioux quartzite. It is exposed only in a few places in the deeper stream channels in the southern part of the area. It has no appreciable influence on either soil or run-off. Above this is the Cretaceous series common to the plains region. It contains the Dakota sandstones, the Benton sandstone and shale, the Pierre shale, etc. This formation also is exposed only in the deep-stream channels, and there not extensively.

The important formation, the one that covers practically the entire surface, is a glacial till. It forms a layer from about 50 to 200 feet in thickness. It is composed of an unstratified mixture brought in by the ice. Except for the moraines the material was well pulverized by the ice and is 90 per cent clay.

Soil.—The surface of the till has weathered uniformly, until now it is covered almost entirely by a rich black loam, varying in depth from few to several inches. The subsoil is uniformly clay. There are a few sandy areas and even a few low sand hills, but their area is negligible.

The surface soil would erode readily if other conditions were favorable, but as it is there is practically no erosion. The only erosion mentioned in soil reports is along the slopes to the stream channels and the slopes along the border of the Missouri Plateau. Professor Hutton, assistant agronomist at the South Dakota Experiment Station, says:

> Very little erosion on any of the types. Slopes are gentle, except along some of the deeper channels, but I know of no marked erosion, unless there might be on some of the slopes east of Yankton.

The remarkable thing about the area is that it shows so little weathering, the surface now being almost as it was left by the receding ice.

CLIMATE

The area has the characteristic semihumid climate of the plains region. Its precipitation as recorded at Weather Bureau stations ranges from 16.65 to 26.37. In general it decreases to the north and west. The variations, however, are by no means regular. The heaviest record is for Aberdeen in the northern part of South Dakota and the lowest is for Howell, about 50 miles to the south. The average for South Dakota is 22.3 inches, while for North Dakota it is only 19.1 inches. Stations near the divide to the west in South Dakota average 20.7, while those near the divide to the east average 22.9.

The average snowfall is 24.7 inches. This does not accumulate on the ground but blows away or evaporates. It has no influence on high waters in the spring.

May and June are the months of heavy rainfall. Means for June run around 4 inches. That for Aberdeen is 4.29, while that for Melville is 3.51. The maximum recorded for Melville is 7.75, while that for Aberdeen is 9.12. These amounts would cause high water but usually not floods. The greatest 24-hour record is 3.92 inches at Huron in Beadle County.

The temperature ranges from −44 to 109. The mean for January in North Dakota is 2.7° and for July is 68.7. For South Dakota the January mean is 11.3 and the July mean 72.6.

Wind is heavy throughout the year but particularly so in April. For this month the average hourly rate is 13.6 miles at Huron. The maximum recorded is 72 miles in January. The average per cent of sunshine is 63 and the average relative humidity, at 8 p. m. in June, is 50. This combination of high wind, high summer temperature, high per cent of sunshine, and low summer humidity gives a very high evaporation rate.

HISTORICAL DEVELOPMENT

Settlement began in the seventies. It was slow until 1887, but from that time on it was vigorous until the exhaustion of public land. The lack of fuel was a great handicap at first. There were no coal and no timber. As transportation developed, it became easier to get coal and the hardships of the early settlers were decreased. During this early period all the trees along the streams were cut. These have since sprouted and, with the planting on upland farms, the woodland area is now much more than it was in the beginning. At present the woodland averages 2.5 acres per farm.

The following table shows the present land usage as reported in the 1925 farm census:

State	Number of farms		Crops, 1925				Farm acres, 1910
	1920	1925	Crop	Pasture	Woodland	Total	
North Dakota	9,704	9,487	3,062,791	908,543	22,057	4,394,487	3,800,252
South Dakota	22,092	23,381	5,811,975	2,006,995	56,299	9,283,001	8,036,111
North Dakota (per cent)			56	18	.4	80	69
South Dakota (per cent)			60	21	.6	96	83

LANDS OTHER THAN FOREST

A. Sixty per cent of the total area is cropped. Of this, spring wheat occupies the largest total acreage. It is somewhat exceeded by the combined acreage of oats, rye, and barley. Flax is also an important crop. Corn is second in acreage but only about half of it is raised for grain.

The regular practice is to plow in the fall. This leaves the bare land exposed throughout the winter. Since there is so little precipitation during this period it seems to have no influence on erosion. By the time the spring rains become heavy, the small grains are started. The bare lands and the heavy winds of winter are conditions favorable to wind erosion, but records do not indicate that it is noticeable except over limited areas. The prevailing soil seems to be too heavy for it to erode badly from wind.

B. The remainder of the land is pasture and wild hay meadow. There is some waste land along streams and in the upland depressions. Most of the latter dry up in time to produce hay but others contain marsh plants of no value or are alkaline.

The area of tame grass pasture is increasing, but as yet the native bunch grasses predominate. The ratio of the number of stock to the number of acres is 1 to 5, which would indicate rather heavy grazing.

CONDITION OF FOREST

There is no native forest type. When the first settlers came they found a few cottonwood groves along the streams. Although these have been persistently cut for fuel and fence material, they still exist, covering much the same areas as they did originally. In addition, there has been considerable planting for windbreaks. Professor Hutton, of South Dakota, says: "Timber areas very small. Probably about what they have always been. Where cut off, usually allowed to grow again. I think the wooded areas are being preserved." The woodland area now averages 2½ acres per farm. It is, in general, well cared for.

PROTECTIVE VALUE

A. *Soil.*—

Area (square miles)	Rating
20, 115 (loam)	75
400 (clay)	50
200 (sand)	100
Average	75

B. *Topography.*—

18,645 (nearly level)	100
2,070 (short slopes)	75
Average	97. 5

C. *Precipitation.*—The total precipitation is low for a farming country, being only 21.2 inches for the area. Although one-third of this falls during May and June, it would still seem to be of not more than medium danger. It is, therefore, rated at 75.

D and E. *Cover.*—

Area, square miles	Rating
3,390 (hay)	100
6,860 (grain)	75
3,249 (corn, etc.)	50
7,086 (grass)	75
130 (forest)	100
20,715, average	75.3

Average rating for watershed, 82.1.

CRITICAL AREAS

There are no critical areas of any appreciable size. There are numerous small areas along streams and old channels that should be protected, although erosion at present is very light.

RECOMMENDATIONS

The area of woodland should be extended to about ten times its present acreage of 5 per cent of its area. It should include the steep slopes adjacent to streams, much of the flood plains along streams, the bluffs along the border of the plateau to the west, and windbreak areas for farm buildings in the level prairies.

In North Dakota this can be accomplished through existing extension agencies. South Dakota should be encouraged to employ an extension forester since the problem is one of planting small areas on existing farms.

Present forest land is in good condition; the need is for extension.

KANSAS RIVER

(Area 55)

LOCATION AND AREA

The Kansas River drainage lies wholly within the plains region. It includes the northern half of Kansas, or about 34,448 square miles, about 8,721 square miles in eastern Colorado, and a strip along the southern border of Nebraska, including 16,541 square miles, making a total area in the three States of 59,710 square miles. It empties into the Missouri at Kansas City and occupies the territory between the Platte and Nemaha on the north and the Arkansas-Osage Rivers on the south. This territory is approximately 480 miles long and averages nearly 130 miles wide. Its greatest width is only 195 miles, which gives it pretty much of a rectangular shape.

TOPOGRAPHY

The entire drainage area is one vast undulating plain tipped to the east, the western end being some 3,700 feet higher than the eastern. The change in elevation is gradual, being only slightly greater in the west than in the east. Local topography, however, is due almost entirely to weathering, and this in turn varies with precipitation and soil. The eastern part, receiving more precipitation, has a more irregular surface. This difference has also been somewhat enhanced by glaciers.

Due to the general tilting of the country, the Kansas and its principal tributaries flow nearly directly east. The one important exception is the Big Blue River, which rises near the Platte, about 80 miles north of the Kansas line. It flows in an easterly course for nearly 60 miles, then turns to the south and southeast and empties into the Kansas River at Manhattan, about 100 miles west of Kansas City. The course of this stream is supposed to have been formed by the water flowing down the west side of the ice sheet that extended south to the Kansas River or just beyond. The basin of the Big Blue has been so badly dissected by this stream and its tributaries, that it has quite a rugged appearance. The valley is from one-half to a mile wide and a hundred feet deep. The hills are only 200 or 300 feet high but being badly cut up, slopes are frequently steep, and the country has the appearance of having a greater range of altitude.

The Kansas River proper has a somewhat similar topography, except that the valley is wider and the hills somewhat higher. Being in the belt of heaviest rainfall, it shows the effect by a greater degree of weathering and more silting up, so that the stream here has very little fall. The valley walls are usually steep and sometimes precipitous, due to the limestone outcrops. In general, however, these have weathered away or been covered up until now only relatively few are visible from the valley.

The western half of the drainage receives much less precipitation and therefore shows much less weathering. Here the two principal streams are the Republican and the Smoky Hill Rivers.

The Republican drainage is gently rolling or level in its western part. The valleys have not cut deeply into the plain, and the slopes are not steep. The uplands are nearly level or only gently rolling. In only a few places has the river or its tributaries cut down through the Tertiary layer. Farther east the weathering process is further advanced and the plain is more rolling.

The Smoky Hill drainage differs somewhat. It is much the same in Colorado but in western Kansas erosion has been much greater. The streams, especially the south fork, have cut quickly through the Tertiary deposits into the Cretaceous. The wearing down of the soft Niobrara layer has been so rapid, that the slopes to the river and its tributaries are steep. This gives a decidedly rought, hilly belt along each side of the river valley. The uplands are nearly level or rolling. Farther east the weathering has extended back farther, giving the entire drainage more of a rolling hilly topography.

These western branches all have a fall of about 10 feet per mile. This gives them a relatively swift current. The valleys are narrow,

fertile, and very desirable for agriculture. There are no swamps or mountains and no natural reservoir sites of any considerable area. The stream beds are usually sandy and shifting. In general, the western two-thirds is one great natural plain only slightly cut up by stream valleys, while the eastern one-third is rolling to somewhat hilly.

GEOLOGY AND SOIL

A. The geology of this drainage area is remarkably simple. There are in a general way three broad belts or zones, due to the exposing of deeper layers by the excessive weathering of the eastern part. The oldest belt which is exposed for 100 to 150 miles in the eastern part of the area, is in the carboniferous system of Paleozoic rock. The most easterly half of this is in the Pennsylvanian series of limestones and shales. Above this, and exposed in the next westernly belt, are the rocks of the Permian series. They, too, are made up of limestones and shales, and the soil resulting from their decomposition is very similar to that from the Pennsylvanian series.

To the west as the elevation increases a newer strata overlying this is reached, which forms the next geological belt. It represents the Cretaceous system, and is composed of several series of sandstones, shales, and clays. In the eastern part the Dakota sandstones are exposed over a strip some 10 to 20 miles in width. West of this the most important are the Richfield sands and the Pierre shales. In the valleys, Niobrara formation is exposed in many places. It consits of a lower layer or limestone, called the Fort Hayes limestone and an upper layer of soft limestones called the Pteranodon beds. These beds are from 300 to 350 feet in thickness and underlying the Pierre shale.

Above the Cretaceous series and covering almost the western half of the drainage are the Tertiary deposits. These deposits are thought to represent a great alluvial fan brought down from the mountains to the west by streams and spread out over the plains. They consist of unequal layers of gravel, sand, silt, and clay, with a minimum thickness of 350 feet. The material is surprisingly uniform when its extent is considered, but there are considerable local variations. There are layers of clay silt, fine and coarse sand, and gravel up to pebbles 3 or 4 inches in diameter. The clays are commonly found several feet below the surface and sands and gravels in the stream depressions. In general the surface uplands are silt.

SOIL

In general, the entire area has a loam soil, the kind of loam depending largely on the geological belt. In the eastern limestone belt there are in the uplands layers of clay. Usually they are exposed only in the narrow belts, but in some places are fairly extensive. Some of these clays are from glacial deposits but in general are formed from the disintegrating shales. There are here also rocky moraines left by the receding ice belt.

In the central belt the clay soils are fewer and less extensive, the soil being uniformly light loams formed from the Richfield and Dakota sands. In places, however, especially in the Richfield soils,

the sand is inclined to predominate and we have sandy loams verging into loamy sands.

In the Tertiary zone the loams still predominate but sandy areas are greatly increased. The soil here is very deep, sometimes three or four hundred feet. The upland soil is uniformly loam, the Colby silt loam being the most extensive, but the slopes to the valleys cut the various layers and give strips of sand, gravel, or even occasionally clay.

The Tertiary soils are subject to cementation, disintegration, and weathering and have therefore changed their characteristics in many ways since they were first deposited. There are also extensive loesses, the weathering of which forms some of the richest loams of the wheat belt.

In the valley soils there is found a mixture of elements from the various formations above. These soils are uniformly loam, but occasionally sandy. The greater the percentage of lime and shale derivatives the greater the tendency to erode, but all are subject to destructive bank erosion at every high water.

The eastern uplands erode most readily and since they receive most precipitation, have suffered most damage. Professor Aldous, of the Kansas State Agricultural College, says that from Junction City east erosion is heavy and many fields have been ruined. This damage, while not so marked, extends into the rolling uplands of the central region. The western areas, while receiving less precipitation, are most subject to torrential rains of the nature that do greatest damage, so the erosion element is not in direct ratio to precipitation.

CLIMATE

The climate in general is remarkably simple, but in detail it becomes complex due to its great variability and the extremely large fluctuations from year to year. For example, the annual precipitation at one station has varied from 7 to 28 inches. The region is subject to extremes and sudden changes.

Temperature ranges from 32° to plus 113°. The mean winter temperature is 29° and the mean summer is 74°. Quick changes of temperature are characteristic.

Precipitation decreases gradually from east to west. At the extreme eastern border the mean is 37 inches, while the maximum is 50 inches. In the west the mean is about 16 inches (no record on the extreme border), with a maximum of 28 inches. In the central part it is 25 inches. Lines of equal precipitation run uniformly north and south. In the western part the ratio of precipitation in the dryest year to that in the wettest year is 1 to 4, in the center, 1 to 3, and in the eastern, 1 to 2.

The six months beginning October 1 has normally just a little less than one-fourth the annual precipitation, and nearly half of this falls in October and March. Beginning in March, the precipitation increases until June when it begins gradually to decline. While May and June have the greatest total fall, the heaviest rains come in July and August, or even in September. During these months torrential downpours are common. These do the greatest damage through erosion and local floods. Hail is also common during this period. There is but little snow and no damage from snow melting except locally.

Due to its position in the return trades and its unbroken topography and lack of cover, the region is subject to severe and continuous winds. The prevailing direction is from the northwest in winter, shifting to the southwest in spring and to the south in summer. During the spring winds are particularly severe and damage to cultivated fields from wind erosion is common from central Kansas west.

With a semiarid climate and heavy winds it follows that evaporation is great. In the extreme west it is annually almost four times the precipitation. This ratio decreases to the east as precipitation increases.

HISTORICAL DEVELOPMENT

Settlement began with the discovery of gold in California. It received its next impetus from the Kansas and Nebraska act. After the Civil War settlement was again active for a time. In the eighties a series of unusually wet years stimulated settlement of the arid areas of the west. The drought years that followed caused wholesale depopulation. After this it increased gradually up to a maximum at about 1910.

In the beginning the extreme eastern part was probably 50 per cent wooded. The proportion of woodland decreased gradually westward until it became practically nothing. The timber was hardwood, oak, walnut, hickory, hackberry, elm, cottonwood, etc., largely unsuitable for lumber, so that there never was any large scale lumbering. There were, however, numerous small portable sawmills that cut low-grade lumber for local use. A considerable amount of cutting, however, was done to clear the land as well as to get the lumber and fuel wood. Clearing has continued up to the present time but can not proceed much further. It is now probably more than balanced by planting. The maximum woodland now for any county is 11 per cent, and the average for the extreme east is 8 per cent.

In the west the limited woodland areas suffered even more but not for the same purpose. The incoming settlers had to have fuel. The woodlands were soon stripped for this purpose. But the native cottonwood was very prolific and persistently held on. Planting soon began, so that now the total wooded area is probably as great as it ever was. In the central part 1½ per cent was woodland in 1925 and one-tenth of 1 per cent in the western part.

The following table shows the land used for crop, pasture, and woodland as given in the 1925 census report:

Land usage—Kansas River area

State	Land usage, 1925			
	Crop	Pasture	Woodland	Total
	Per cent	*Per cent*	*Per cent*	*Per cent*
Western	20	31	0.1	63
Central	54	31	1.5	89
Eastern	54	30	8.0	92

The woodland now occupies, as it should, the poorest land. This was not intentional but is the result of the natural tendency to clear the best land first. However, clearing has proceeded too far in the western part, and much damage is being done by erosion. At least twice the present area should be in woodland. These critical areas, however, that should be kept wooded are all small, seldom more than 50 acres in extent, so that it seems to be a permanent wood-lot area.

The stream valleys, particularly in the eastern part, are subject to flood damage, but since this is the very best agricultural land, it is not probable that they will ever be forested. The value of the land is such on the main river itself that masonry works for stream-bank protection would be cheaper than forestation. This has been resorted to in places and probably will be used to a greater extent in the future. In the west, county agricultural agents advocate stream-bank planting by public agencies.

The condition of the forested area is very poor from a wood-production standpoint, but for protection it seems fairly adequate, although there is some gullying in wood-lot areas.

LANDS OTHER THAN FOREST

A. In the eastern area the crops are the ordinary diversified crops of the western Corn Belt. Corn predominates, but not to the same extent it did 20 years ago. Corn, being cultivated in rows, places the land in condition more favorable to erosion than other crops.

In the West wheat predominates. Throughout this region, except for limited areas, wind erosion is more noticeable and more damaging to crops than water erosion. Areas, however, in dry draws, on steeper slopes, and the breaks of hills, are being damaged by gullying.

Planting in this region has been almost wholly for windbreak purposes and therefore from the protection standpoint on the land least in need of it. Planting for soil protection should also be encouraged. There are no large areas, however, where planting for this purpose would be desirable.

B. The pasture land on the farms, as reported in the 1925 farm census, held quite uniformly around 30 per cent. The unreported land, however, is largely pastured. This greatly increases that per cent in the West. Tame-grass pastures are increasing in the eastern part. In the western half a large part, reaching 68 per cent in the extreme west, is grazing land. This is not so well cared for. Professor Aldous estimates that carrying capacities have decreased one-third. This indicates overgrazing. In many cases large pastures are being cut by deep gullies. These start from trails or in areas in heavy use. Control would, of course, be advantageous in preventing injury in the future.

CONDITION OF FOREST

The forest is entirely upland hardwood. The red cedar is the only native conifer. It never occurred to any considerable extent and is now nearly gone except where planted. There are no extensive areas and no cutting except for local use on the farms and a small amount of fuel wood.

A. *Effect of lumbering.*—Lumbering has never been carried on in the area. The original forest was poor in quality but occupied good land. It has, therefore, been cleared. As near as can be ascertained, only about one-fifth of the original area is now forested. Most of the land cleared was agricultural land, but a considerable part was "border line" in quality and soon deteriorates. It is not being abandoned as crop land. The best would make pasture land if seeded and cared for, but possibly a fifth should be reforested. As has always happened, clearing was carried too far.

B. *Effect of fire.*—Fire has never been a problem. Now the wooded areas are so small and so interspersed with field and roads that fires are unknown.

C. *Effect of grazing.*—Practically all wooded areas are grazed. This keeps down reproduction and breaks up the forest floor, but as far as erosion is concerned, it has not yet destroyed its protective value, yet there is some erosion in wood lots. Pasturing will continue until the wood-production value increases. Extension workers should inform owners as to the economic value of wood lots and injuries due to grazing.

D. *Effect of drainage.*—There are no swamp areas and no drainage.

E. *General summary.*—The forest has now been reduced to a small wood-lot basis in the east. In the west, some planting is being done, but for windbreaks rather than protection.

PROTECTIVE VALUE OF WATERSHED

A. *Soil.*—In the west the soil is a light sandy loam, interspersed with sandy areas. From the soil maps available it is estimated that two-fifths of the area, or 1,260 square miles, is sandy. In the eastern third there is considerable clay or heavy loams that erode readily. These are in small tracts. It is estimated that they aggregate 630 square miles.

The remainder, including the central portion of the watershed, has a deep loam soil that readily absorbs water. It erodes, but can be controlled by proper methods of cultivation and crop rotation.

Area (square miles)	Rating
5, 997	50
11, 993	100
41, 720	75
59, 710	--------

Weighted average, 77.5.

B. *Topography.*—A large part of the area is an unbroken level plain. Slopes are very low. There are numerous small retention ponds built by stockmen. Further, the Kansas Water Commission, after several years' study, class the western half as nonflood contributing territory. Fifty per cent of the area is, for these reasons, classed as high.

The bluffs bordering streams in the eastern half and along the Smoky Hill River in the west, also local hilly areas, are classed as

low. These equal two-fifths of the total area. The remainder is medium.

Area (square miles)	Rating
Per cent	
20	50
50	100
30	75
100	----------

Weighted average, 82.5.

C. *Precipitation.*—The precipitation in the eastern third is heavy during spring-flood periods and is normally flood contributing. It is classed as low. The western third is light and noncontributing during flood periods and is classed as high. These factors balance and leave the factor for the area at medium. Rate equals 75.

D and E. *Cover.*—The 1925 farm census gives the hay land as 2,380 square miles; corn, potatoes, and other crops cultivated in rows is 8,614 square miles; while the remainder, 48,716 square miles, is pasture land or not reported.

Area (square miles)	Rating
2,380	100
8,614	50
48,716	75
59,710	----------

Weighted average, 72.4; average rating for the basin, 76.8.

CRITICAL FOREST AREAS

The critical areas are all small, only a few acres in extent. However, there are many of them and their total influence is great. They are all privately owned and parts of farms. The only method of control seems to be through educating the owners as to losses from erosion and methods of control. This is being done through the department extension service, in cooperation with the States.

RECOMMENDATIONS

A. All of the remaining wooded areas should be kept permanently so. This area should be doubled in the east half, primarily for erosion control. To do this effectively will require detailed study of individual farms. This should preferably be done under the direction of State extension foresters.

In the western half planting for wind protection should be pushed and in addition attention should be given to erosion control. In many places particular attention should be given to stream banks and low flood plains. Increased cooperation with State extension services seems to be the practical method for handling the problem.

B. *Measures necessary.*—Protection from fire, insects, etc., is not a problem. Methods of wood-lot cutting could easily be improved. Erosion is serious on agricultural land, as well as areas that should be wooded. It should be approached by a comprehensive plan, including the concurrence and receiving the cooperation of all interested agencies, including soil, crop, and range experts, as well as foresters.

FLOYD AND LITTLE SIOUX

(Area 56)

LOCATION AND AREA

The Floyd and Little Sioux Rivers are tributaries of the Missouri. The Floyd empties into the Missouri at Sioux City, Iowa, the Little Sioux about 15 miles south of Onawa. These rivers, flowing in a southwesterly direction, drain 5,451 square miles in northwestern Iowa and 350 square miles in southern Minnesota, a total of 5,801 square miles.

TOPOGRAPHY

This drainage area has but one primary physiographic form—the prairie plain. The relief is slight, varying from about 1,000 feet at its lowest point to slightly over 1,600 feet in the northern portion. The divide between the Missouri and Mississippi River drainages enters Iowa from the north a few miles east of Spirit Lake and passes southward through the eastern parts of Dickinson and Clay counties and thence through Buena Vista, Sac, Carroll, Guthrie, and Adair counties. This divide is a broad, flat, and inconspicuous ridge. Its southern extension is somewhat better defined.

The streams within this area all have shallow and broad upper valleys, but in their lower portions they have deep valleys of erosion. Near their mouths and at various places along their courses, the process of erosion has caused the walls of the valleys to recede so as to form broad alluvial flood plains covered with fertile soil.

Erosion finds extremest illustration in the deep-cut valley of the Little Sioux.

In the northern portion, where erosion is slight, are many lakes, swamps, and marshes, caused by the deposition of drift material and detritus by some great glacier or ice sheet. Drainage has caused many of these swamps and marshes to disappear, and cultivated fields have taken their place.

GEOLOGY AND SOILS

A. *Geological formations.*—Originally this part of Iowa and Minnesota was an old sea floor. The alternating layers of sands, muds, and lime deposits by which it is underlain were slowly cemented and consolidated into sandstones, shales, and limestones, and raised by gentle uplift into the great interior plain sloping southward. The surface irregularities are largely the result of long-continued erosion by weather and running water, the effects of which have been greatly modified and almost obliterated by glacial ice.

The original geological formations in this region were overridden by glacial ice at least twice during the glacial period. The general effect of the icework was to wear away the more sharply defined prominences, to fill the valleys, and to spread rock waste over the area. This mantle of drift varies in thickness from 100 to 200 or more feet. The material thus deposited is a mixture of clay, sand, pebbles, and bowlders of all kinds.

Overlying the drift sheets of earlier ice invasions is a fine porous clay called loess. This formation is wind formed, probably, and can be readily distinguished from the underlying drift by its lack of pebbles and bowlders. It tended to smooth out the slight irregularities of the drift sheets on which it was deposited.

These coverings of glacial material and loess are subject to erosion much more readily than the original underlying formations, and such surface irregularities and deep-cut valleys now existing are largely the result of the action of weather and run-off water.

B. *Soils.*—The soil of this region is for the greater part a rich black, fertile loam, derived from the glacial deposits or the loess covering as subsoils. The depth varies. On many of the steeper slopes the loess covering has been removed. The larger valley floors are filled with sands and gravels overlain by alluvium. These soils are comparatively easily eroded. This is evidenced by the strikingly increasing depth of the river valleys as they near the Missouri River Valley.

CLIMATE

This area has all the essential factors of climate to make it one of the most productive agricultural districts in the Union. The precipitation averages about 27 inches. During the six crop months—April to September—71 per cent of the annual precipitation occurs, and during the four months of principal crop growth—May to August—fully 52 per cent of the annual amount occurs. From November to March the precipitation is light and only about 20 per cent of the annual amount, mostly in the form of snow. Much of the rainfall comes in the form of gentle showers, but occasionally heavy rainfall is general over the region and continues for one or two days. Many of the summer showers are attended by thunder and lightning and a few by heavy downpours of rain. The heaviest rainfall recorded within this area within 24 hours occurred at Primghar on July 14–15, 1900, when 13 inches fell.

The average annual temperature of northwest Iowa, which is quite applicable to this area, is 47.4°. Separated by seasons, the average is: Winter, 20.8°; spring, 47.5°; summer, 71.7°; autumn, 49.7°.

The average annual range of temperature amounts to about 136°. Maximum temperature recorded for the general area is 113°, minimum −47°, but these extremes are unusual for the territory.

The surface of the ground is sufficiently frozen to prevent ready absorption of rainfall for about 4½ months of the year.

Only a small proportion of the precipitation occurs during the period when the ground is frozen and a very large proportion, probably about to 80 per cent, falls in late spring and summer when absorption is greatest. The heaviest rainfall also occurs during the

seasons of the preparation and cultivation of the soil, thus greatly increasing the absorption.[1]

The forested portion of the area is confined to narrow belts along the streams and shores of the lakes. In the lake region the shores of nearly all lakes of the system are fringed with timber which at the time of the first settlements consisted of very large trees, mostly white oak. The larger trees were cut down by the early settlers, sawed into lumber, and used in the building of homes. The present forests are for the most part second-growth timber, including a variety of hardwood species, such as oak, ash, hickory, black walnut, cottonwood, maple, and box elder.

The original forests of Iowa are estimated to have covered 15 to 17 per cent of the State. In the northwest portion alone the percentage of native forests was probably considerably less than 15 per cent. Some natural timberlands have been cleared, and planting of groves around farm buildings has added to the area; 1925 census figures show that approximately only 2.3 per cent of the area within this drainage is covered with forest growth. This forest area is almost all included in farms, and all is privately owned except possibly timbered parks owned by towns or cities.

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[1] During the past 30 years Weather Bureau records indicate that excessive rains, each in excess of 4 inches, and recorded for at least one or more stations within this unit, have fallen as follows:

August 6, 1898.
May 27–28, 1899.
June 26, 1899.
August 12, 1899.
May 31, 1900.
June 16, 1900.
July 14–15, 1900.
September 11, 1900.
July 8, 1902.
August 26, 1903.
September 18, 1905.
June 27, 1909.
July 10, 1909.
May 10–11, 1912.
August 16–17, 1912.
September 9–10, 1914.
May 25, 1915.
July 18, 1915.
September 26, 1915.
July 13, 1919.

Of these, several storms are outstanding in that they covered considerable territory with precipitation records as follows:

Date	Place	Precipitation
		Inches
June 24, 1891	Larrabee	12.99
	Alta	8.30
July 14–15, 1900	Primghar	13.00
	LeMars	5.39
	Alta	4.75
	Onawa	4.42
Sept. 11, 1900	Primghar	4.25
	Larrabee	4.35
	LeMars	5.50
	Sheldon	5.75
	Sibley	4.00
	Sioux Center	5.90
	Spirit Lake	5.98
	Onawa	4.65
Sept. 18, 1905	Sioux City	4.29
	Alta	6.10
	Larrabee	5.50
Sept. 9–10, 1914	Sioux City	4.65
	Alta	4.08
	Washta	4.60
	Odebolt	7.00

General rains over this section, much smaller than those named above, are of common occurrence and result in high water in the streams. All such high waters result in considerable material being carried down by the stream, but data on amounts of silt carried down during times of flood are not available.

Erosion of the soil is not severe except on the steeper slopes, and in such places the excessive rains which are of common occurrence do a good deal of local damage largely in the form of gullying and bank caving, caused by rushing of water down steep surfaces.

References: U. S. Geological Survey Water Supply Paper No. 293; U. S. Census, Iowa, Statistics by Counties; Iowa Parks, report board of conservation; Weather Bureau, Summaries of Climatological Data; Annual Reports, State geologist of Iowa.

CONDITION OF LANDS OTHER THAN FOREST

(*a*) As shown by the 1925 census figures, about 67 per cent of the area within this drainage area is crop land. The principal crop raised in this region is corn. The cultivation of the land for this crop is such as to absorb as much moisture as possible. Erosion of the soil, especially on steeper slopes, is considerable in times of heavy rains, but reasonable precaution is taken to avoid erosion in all cultivated lands.

(*b*) The unimproved lands are made up largely of the rougher lands used for pasture, swamps, etc., and will account for about one-fourth of the area. On such lands the effect of erosion has been greatest in that the watercourses have worn deeply through the soil and subsoil to an extent that the slopes are too steep to be cultivated. The grasses and other vegetation tend to protect them from eroding excessively. Fire is not a serious problem, as areas for pasture are scarce and forage is fully utilized—in places to the extent that overgrazing has resulted in severe erosion in localized sections.

CONDITION OF FOREST

The forests of the region may be classified under the one type—upland hardwood type. This would apply to the natural woodlands as well as planted groves which, while in small individual tracts, are scattered all over the unit.

(*a*) *Effect of lumbering.*—The cutting over of the forests in this region resulted in the removal of the larger trees which were suitable for saw logs during the earlier development of the country. Second growth has taken place of the original forests and in time will, with protection, equal the original stand.

(*b*) *Effect of fire.*—Fires are no longer a problem in this region, either in grass or in the woods.

(*c*) *Effect of grazing.*—Grazing is limited largely to small numbers of stock on practically every farm. Dr. L. H. Pammel, botanist of the Iowa State College, states that the pastures are generally overstocked, and that 75 per cent of Iowa pastures are overrun with small ragweed. He also reports that unpalatable plants are increasing.

(*d*) *Effect of drainage.*—Some drainage has been done in the lake section of northwestern Iowa and along the flat flood plain bordering the Missouri. This drainage has been for the purpose of lowering water levels on swamp areas and to make the land available for farming. Along the Missouri flood plain the flat nature of the land causes water to remain on valuable farm lands in times of heavy rainfall, and considerable damage of this nature has been done. The effect of artificial drainage on such local areas is to lower the water table and to hasten surface run-off.

(*f*) *General summary of forest conditions through the drainage area.*—The forests are in general confined to natural timber along water courses and bordering lake shores. This growth is of mixed hardwoods and occupies, along the streams in particular, the rougher and more steep portions of the area, where its beneficial effect from the standpoint of checking erosion is greatest.

PROTECTIVE VALUE OF THE WATERSHED

Average rating for the basin is as follows:

	Protective rating
(*a*) Soil	75
(*b*) Topography	90
(*c*) Precipitation	74
(*d*) Nonforest cover.	
(*e*) Forest cover, hardwood upland type only, (combined rating given for captions *d* and *e*)	69
Average rating	77

The protective value of this watershed rates relatively high for the plains region. The cultivated lands for the greater part are comparatively level and absorb precipitation more readily than on steeper slopes. Forested land and pasture land make up a large portion of the steeper sections of the area which would be more susceptible to erosion and heavier run-off without the beneficial influence of the sod and forest conditions.

CRITICAL FOREST AREAS

There are no data available to indicate the existence of any areas where erosion or flood conditions are critical. The impression gained from reviewing the report of the Board of Conservation on Iowa Parks is that the original forest area of Iowa is decreasing and creation of a series of State parks is desirable to preserve natural forested areas of especial scenic beauty. No such recommended park areas are, however, within this particular watershed.

There are unquestionably numerous small local areas which would be considered as critical forest areas where forest planting would improve erosion, flood, and run-off conditions.

Also there is apparently a tendency to speed up the run-off water on areas subject to periodical flooding in times of heavy rains in portions of the area, particularly in the lake and swamp region in northwestern Iowa and in the broad, almost level, flood plain along the Missouri River. Without artificial drainage much valuable farm land is so wet that crops can not be successfully grown. There is, therefore, a desire to get rid of surplus water in the shortest possible time, which practice probably adds appreciably in the aggregate to high water in rivers in times of excessive rainfall.

State Extension Forester I. T. Bode, of Iowa, is quoted as follows:

> I believe there are many places of considerable area where timber and brush should be extended. There are large areas of overflow and large areas of very steep bluff land, especially along the Big Sioux and Missouri, that should be protected as public property. Types of this exist around Council Bluffs and Sargents Bluffs.

Also under general comments on action that may be advisable to reduce run-off and erosion, he says:

> I feel that large areas of these Missouri loess bluffs should be public property. They furnish only second-rate grazing, mostly because the grass dries early in season and is apt to be thin. There is a question whether they can ever be made to produce timber growth, although the same now exists along streams and in coves.

RECOMMENDATIONS

The area to be retained in forest should under no condition be reduced but rather increased by additional planting for windbreaks and shelter belts on farms, as may be needed. Also planting of trees on the steeper hills and slopes for protection where excessive damage from erosion may be present, is recommended. With sufficient protection from overgrazing, most areas naturally suited to forest growth will in this region restock themselves naturally to tree growth, and if given a little encouragement nature will itself largely take care of really essential reforestation. Figures taken from the Iowa 1925 agricultural census indicate that about 2.3 per cent of the area is timbered, making a total of approximately 133,000 acres of timber in the unit. This includes largely natural timber growth, but also counts in the farm wood-lot plantings.

Protection of forests from fire is a minor problem in this region because of natural favorable conditions. Likewise protection from insects, diseases, wind, etc., does not require much attention.

Proper management of cutting to insure prompt restocking is essential to avoid further decrease of the forest area. The State should have some control over such cuttings to avoid possibility of serious after effects due to cutting of timber unwisely.

The planting of wood lots on farms is recommended on all lands not adapted to cultivation and on all areas where erosion is damaging lands. Extending and liberalizing the provisions of the Clarke-McNary law should be considered, as a means of further increasing and aiding forest planting.

Grazing of woodlands is the general practice in this region and is having a detrimental effect in holding down natural reproduction and disturbing the forest conditions to an extent that the beneficial influence of the forest is at least partially lost. Educational campaigns to reduce erosion and damage to forest growth through grazing should be undertaken by State extension departments.

The average annual snowfall for Iowa is 29.2 inches, or less than one-tenth of the precipitation. Melting snows therefore are not an important factor in the cause of floods for this area.

HISTORICAL DEVELOPMENT

This region is by nature best adapted to agriculture and from the earliest settlement of the territory this has been the chief industry. Census figures for 1925 show that approximately 92 per cent of the area is included in farms.

The first actual settlers came into the lake region of this area in 1856. This settlement consisted of 40 or more men, women, and children. Timber and water were the important considerations in the selecting of lands by these early settlers. In March, 1857, the Spirit Lake massacre occurred, which resulted in the killing by Indians of about 40 people and the complete destruction of the settlement. Subsequent settlement and development of the country was rapid. Railroad construction followed the settling of the region, and in the early eighties the first railroad in the lake region of northwestern Iowa was in operation. The territory along the Missouri River had railroad service as early as 1872.

MISSOURI RIVER (DIRECT)

(Area 57)

LOCATION AND AREA

The area considered as direct Missouri drainage includes the Vermillion River drainage and a strip averaging 35 miles wide along the east side of the Missouri from the Cheyenne River south in eastern South Dakota; also the Bad River drainage and a 20-mile strip west of the river. This strip extends south, averaging 12 miles in Nebraska and 15 miles in Kansas, to the mouth of the Kansas River. It includes also the southwest corner of Iowa, roughly a rectangle 90 by 80 miles. The area in South Dakota is 15,670 square miles; in Nebraska, 6,326 square miles; in Kansas, 1,542 square miles; in Iowa, 7,890 square miles; making a total of 31,428 square miles.

TOPOGRAPHY

Although the area follows the river for nearly 700 miles, the topography is fairly uniform. Along the river is a valley from 1 to 5 miles wide; back of this is a strip of relatively rough land, bluffs, or rather steep hills, badly cut up by the drainage. These rise from 50 to 200 feet above the bottoms. Back of this is a rolling upland area. The rise above the river is seldom more than 400 feet. In South Dakota it reaches a maximum of twice that amount in the Bad River drainage.

The river has a fall of 1 foot to the mile. For so large a stream this gives it a fairly swift current. The Vermillion River of South Dakota is about the same. The rivers of Iowa fall about 3 feet to the mile, while the Bad River has a fall of 8 feet. Other streams are short and very small. Slopes are steep but short, adjacent to the bottom lands along streams. West of the Missouri in South Dakota the general topography is quite rugged and broken. While these areas contain considerable fairly steep land from which there is heavy run-off, they contribute but little to flood crests, since, being so close to the main stream, they have discharged their flood water before that from the main tributaries arrive. Only in exceptional cases are the streams of these areas high at flood crests on the Missouri.

GEOLOGY AND SOILS

East of the river the geology of the area has but little influence. It lies within the glacial belt and the soil is either glacial till, Missouri loess, or bottom-land silt. In South Dakota it is the former, and in Iowa it is 75 per cent loess and 25 per cent bottoms. Only in a few places have the streams cut through this cover to underlying bedrock.

The portion west of the river has also in part been glaciated. But here the cover of till is not so thick. Most of the stream beds have cut through it, penetrating to deeper layers. In Kansas and southeastern Nebraska this exposes carboniferous rock, mostly in the Permian series. Farther north the land lies in the Cretaceous zone, represented largely by the Dakota sandstone, the Pierre shale, the

Benton shales and sandstone, and to a much less extent the Niobrara limestone. The Pierre group predominates.

The soil in Iowa is uniformly a medium to heavy loam. There are a few patches of clay, but these do not include 1 per cent of the area. Three-fourths of this is loessial in origin and one-fourth a bottom-land silt laid down by the streams. About 20 per cent of the loess area is in what is known as the southern Iowa loess and the remainder in the Missouri loess. It produces a rich loam and is practically all farmed.

In Bulletin No. 183 of the Iowa State College it is stated that the southern loess is much more liable to erosion than the Missouri loess. Both gully badly when erosion is once started. In this bulletin it is stated also that "Near the Missouri River erosion is not important. At a distance of two or three counties from the river" (near the east boundary of this area) "the loess thins out and erosion may be serious."

In contrast with this view, the State extension forester says, "About 25 to 30 per cent of a 30-mile strip along the Missouri is hilly and is grassland. Erosion occurs easily. The fine loess soil dissolves away like sugar. Nearly all the smaller streams and tributaries work back into the soil with straight banks and a deep abrupt break at the head. Washing away of the soil is a real farm problem."

The latter is based on more recent but less detailed observations.

In eastern South Dakota the conditions are much the same, except that the bottom land is much less. The soil is uniformly a loam with clay subsoil, both derived from glacial till. Slopes are usually not steep and are short. Erosion is almost unknown, according to J. G. Hutton, associate agronomist at the Brookings Experiment Station.

In Kansas and Nebraska the soil is largely loam, but contains some clay and some rough rocky land. The latter is caused both by outcrops and by glacial bowlders. In the bluffs bordering the Missouri bottoms slopes are steep, though short, and erosion is a problem. In the southern part many fields have been abandoned or turned into pasture land, and many others are being injured. The noncultivated land does not seem to erode.

In South Dakota the soil is largely Pierre clay or the heavy Pierre loam. It erodes readily, and everywhere along the slopes and breaks erosion is a problem. The upland benches and mesas have not yet begun to erode.

CLIMATE

The climate varies from semihumid in the southeast to semiarid in the northwest. Precipitation ranges 15.08 inches at Cottonwood, S. Dak., to 37.28 inches at Kansas City. In Kansas the average is 34.79; in Nebraska, 30.61; in Iowa, 31.29; in eastern South Dakota, 22.46; and in western South Dakota, 17.66.

In all parts the winter precipitation is light, the bulk falling during the growing period. Snow has little if any effect on floods. The heavy precipitation period is in April, May, and June. These months receive nearly half the total. Heavy downpours occur most commonly in July and August. There is great yearly variation, especially in the northwest. At Pierre, for example, the driest year recorded had 7.82 inches and the wettest 23.57. The wettest month was 6.12, and the greatest 24 hours of record is 3.72.

Wind is heavy, particularly in the spring months. The average velocity in April, at Pierre, is 12.1 miles per hour. This, with low humidity and high per cent of sunshine, produces excessive evaporation. In the extreme northwest it is more than three times the precipitation.

HISTORICAL DEVELOPMENT

As the area is in the prairie States, it was settled almost entirely by farmers, except in South Dakota, where the stockman preceded the farmer. There has never been any lumbering or clearing of land other than for farming. In general the bottom lands have been cleared for years, but hillside land is still being cleared. On the other hand, some of the poorer lands have been abandoned and brush and tree growth are coming back. In South Dakota the woodland area is probably as great as it ever was.

The following table shows the use of land as reported in the 1925 census of agriculture:

	Crops	Pasture	Woodland	Total land area	All land in farms
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Kansas	58.8	23.4	5.8	4.9	87.5
Nebraska	61.1	22.5	4.1	20.1	90.4
South Dakota	38.1	27.5	.6	49.9	68.7
Iowa	62.7	25.8	3.6	25.1	93.4
Total	50.1	25.8	2.3	100.0	79.9

It is not likely that the present acreage of timber will be greatly increased although some planting is being done within the area.

LANDS OTHER THAN FOREST

The condition of the nonforested land differs considerably in the various States, although the percentage in crop, pasture, and woodland is practically the same for Kansas, Nebraska, and Iowa. Kansas had originally the heaviest timber and has suffered most from clearing. The broken hills bordering the stream bottoms were well wooded. These had a thin soil usually with a clay subsoil. After clearing, the topsoil was apt to wash away leaving a field with very low fertility, if not one badly gullied.

Professor Aldous, of the Kansas State Agricultural College, says that erosion is bad and many fields are being abandoned. The present woodland cover is 5.8 per cent of the area. In Nebraska, conditions are similar but apparently not quite so extreme. Sixty-one per cent of the area is cropped and 23 per cent pastured. There is little erosion in pastures, but fields when not properly handled erode badly.

In Iowa 63 per cent is in crops and 26 per cent in pasture. The State is working on the erosion problem through education and demonstration. As quoted above, the soil specialists do not consider it serious while the State forester does. The soils men are recommending various means for control. They recommend alfalfa for the steeper slopes, while the forester recommends trees. It is likely that the State will work out the problem successfully in its own way.

In South Dakota the agronomists say there is no serious erosion in the glaciated region. This region is only about 50 per cent cropped, because of low precipitation in the northern part. The remaining land is grazed but not heavily. Woodland is increasing somewhat but is still less than 1 per cent of the area.

West of the river, in South Dakota, conditions are radically changed. The per cent cropped is low, 22 per cent, and that largely to forage crops. Stock raising is the chief industry. The uplands, when not cropped, are well grassed and are not suffering. The breaks to the streams are steep and poorly covered. Here erosion is severe, but due to natural causes rather than use. Usage of any kind increases erosion. Trees will not grow. Native grasses will not hold the soil. While these breaks contribute both water and silt during flood periods, it seems that the damage done is far less than the cost of prevention.

CONDITION OF FOREST

There are no forests of any appreciable area. Only 2.3 per cent of the area is woodland. This is in small farm wood lots and in fringes of cottonwood and box elders along the streams. The bottom lands are cleared. From a protection standpoint the woodlands are in good condition, but for production they are not. Practically all are grazed and occasionally trails start erosion. There is no fire danger or lumbering. Wood is cut for fuel and fencing. Occasionally an area is being cleared. On the other hand, windbreaks and groves are being planted and in places brush land is being extended. Forest planting could be used to advantage as a protection from erosion, but possibly other means will be found. Most of the control measures now recommended involve other methods, but trees still have their place. The nature of the eroded soils themselves will eventually increase the woodland.

PROTECTIVE VALUE OF WOODLAND

A. *Soil.*—

Area (square miles)	Rating
7, 187	50
24, 241	75

Weighted average, 69.3.

B. *Topography.*—

Area (square miles)	Rating
9, 567	100
4, 809	50
17, 052	75
31, 428	

Weighted average, 78.8.

C. *Precipitation.*—

Area (square miles)	Rating
4,371	100
3,496	50
23,561	75
31,428	

Weighted average, 75.7.

D and E. *Cover.*—

Area		Rating
Square miles		
3,946	Hay and forest	100
6,765	Corn, potatoes	50
20,717	Grain and pasture	75
31,428	Weighted average	72.8

Average rating for area, 74.2.

CRITICAL FOREST AREAS

Like other agricultural areas critical areas are small. In Nebraska, Kansas, and Iowa there are numerous small areas from one to several acres in extent that are either eroding or in danger of erosion that should be protected. Usually there are one or more on each farm. East of the river, in South Dakota, critical areas are fewer; west of the river they are more numerous and larger. Here forest planting might be extended in the southern part, but would probably be unsuccessful in the north and west.

There are also numerous small areas along the bottom; in fact, the entire bottom might be critical, but it is too valuable for forest planting. The value of the land would pay for other forms of protection. In the Bad River drainage there seems to be no method of checking erosion. The question should be studied on the ground and tests made, including tests in forest planting.

One of the greatest needs is for the various agencies interested in this problem to get together on their recommendations. The Iowa Experiment Station Bulletin No. 183, page 388, recommends against the use of trees in erosion control, while the State extension forester, in his questionnaire, states that he believes timber and brush land should be extended. Conflicting recommendations from Government and State officers can not help being confusing to landowners.

The Iowa State extension forester believes that large areas of the bluff land adjacent to the Missouri and Big Sioux Rivers should be in public ownership.

In other States the conflicting opinions exist but are not so marked. South Dakota should have an extension forester.

The determination of critical areas will require detailed field examination, not of regions but of individual farms.

RECOMMENDATIONS

A. Landowners should be encouraged, through a campaign of education, to retain existing areas as forest. This campaign should not stop there but should inform owners as to the value of extending wood land for protection to deteriorating lands and for wind protection.

Areas which need protection amount to approximately 10 per cent in Iowa, 15 per cent in Kansas and Nebraska, and 5 per cent in South Dakota.

B. In addition, the educational measures should include information as to the economic value of wood land aside from soil protection and also methods for keeping such land productive, particularly with reference to grazing.

NIOBRARA RIVER

(Area 58)

LOCATION AND AREA

The Niobrara River heads in Wyoming but receives very little water from that source. It parallels the north boundary of Nebraska until it flows into the Missouri in Knox County in the northeastern corner of the State. The area of the basin is 10,141 square miles in Nebraska, 1,173 in South Dakota, and 561 in Wyoming, a total of 11,875 square miles.

TOPOGRAPHY

The Niobrara is only a few feet wide at the Wyoming line and remains a small stream until the sand hills are reached. In the western part of the State it drains the northern part of the slopes of the Boxbutte table and the southern slope of Pine Ridge, which consists of a rolling country, broken in many places by patches of Bad Lands. In this region the bottom lands are narrow and cut by many incoming streams. Where the Niobrara enters the sand-hills region, the flood plains are almost overwhelmed by the constantly encroaching sand, so that there is left only a narrow flood plain that is kept scoured out by the stream. Throughout its course from the point at which it enters the sand hills to the eastern edge of the area, the river has cut down into the indurated strata of Arickaree formation producing a gorge-like channel, with areas of rough broken land along the slopes. The bottoms widen out toward the Missouri, but the soils are sandy, owing to the large quantity of material brought from the sand hills.

The river is not subject to periodic rises of any importance owing to the fact that the sand hills, which form so large a portion of its drainage area, act as storage reservoirs for the rain and snow, which are afterwards fed to the stream in the form of spring water, thus equalizing the flow and making the constancy of the discharge almost phenomenal. There are numerous lakes throughout the sand hills which serve as natural reservoirs. The level of these lakes fluctuates

according as there happens to be a cycle of wet or dry years, but these lakes always have water in them.

The stream throughout its entire course flows through hills and rolling lands. The lower course of the river is wider, more shallow, and less even in discharge.

The river enters the State at an elevation of about 4,500 feet and the mouth is about 1,200 feet above sea level.

GEOLOGY AND SOILS

Nebraska is a portion of a vast plateau, forming the Great Plains, which slopes away from the Rocky Mountains. The eastward induration of the plateau is at an average rate of 12 feet per mile. Its surface formations are made up of sediments brought down from the elevated region to the west. Wind has been a more active agent of soil formation than water and the sand hills, through which the Niobrara flows, owe their extensive deposition to this force.

The prevailing soils of the basin are dune sand, sandy loam, rough stony land in the upper and middle courses, and areas of finer-textured soils in the lower course. The soils of the lower Niobrara are erodible but the flow of the river is so constant that any erosion that occurs is purely local.

The soils of the South Dakota portion of the drainage consist of dune sand, Rosebud fine sandy loam, and silt loam.

The soils of the Pine Ridge section of the drainage range between stony land and the Rosebud very fine sandy loam.

CLIMATE

The precipitation in the Niobrara watershed varies from 24 inches at its mouth to 16 inches at its source. About 68 per cent of the precipitation falls during the period April to August, inclusive, and about half of the remainder is snowfall. May and June are usually the months of greatest rainfall. Evaporation is 6, 5, and 4½ feet in the upper, middle, and lower portions, respectively.

The extremes of temperature are quite marked. The temperature frequently drops to 20° to 30° below zero and reaches a maximum of 100° or more. Valentine, which is centrally located on the river, has a mean annual temperature of 46.5°.

HISTORICAL DEVELOPMENT

The Niobrara watershed has been for many years an important stock-raising center. The sand-hill region is devoted almost exclusively to the raising of beef cattle, although dairy herds are now beginning to replace beef cattle in many places. Wild hay and alfalfa are the principal crops, the bulk of the land is in pastures, and the native sod has not been broken. Potatoes, corn, and small grains are raised in the upper basin. In the lower basin corn, alfalfa, and small grains constitute the bulk of the crops.

A strip of nine counties, extending from the west boundary of the State to the mouth of the Niobrara, showed the following classification in the 1925 Agricultural Census:

Crop land:	
Acres	2, 240, 928
Per cent	25
Area in pasture:	
Acres	6, 115, 556
Per cent	68
Area in woodland:	
Acres	295, 918
Per cent	3. 3
Total farm land: Acres	8, 902, 108
Total area: Acres	10, 649, 600

Land classified as "Other" comprises the remaining 3 per cent. The proportion in pasture is greater in the western counties, averaging 77 per cent. Most of the wood lots are also used for pasture.

The largest proportion of forest occurs in Dawes County, amounting to 8 per cent. This is the location of the deeply eroded Pine Ridge country on whose bluffs, slopes, and valleys the western yellow pine finds a favorable seed bed and growth conditions. Most of the mature timber has been harvested, but there is an abundant second growth, despite the grazing of cattle and the attacks of the pine-tip moth.

Western yellow pine also occurs in the river valley and on the adjacent slopes from the Pine Ridge in the northwestern corner of the State, almost to the mouth of the river. Eastern red cedar is also found in mixture, together with burr oak, green ash, American and slippery elm, hackberry, cottonwood, and other species. Along the lower portion of the river valley a larger number of hardwood species are to be found as well as planted forests of pines, cedar, and hardwoods. There are not many planted forests in the western third of the drainage.

The Niobrara division of the Nebraska Forest is located between the Niobrara and Snake Rivers. It is within the sand hills, which are natural storage reservoirs for water. About 12,000 acres have been planted to western yellow pine and jack pine.

CONDITION OF LANDS OTHER THAN FOREST

Alfalfa and wild hay are the principal crops in this watershed. There is little or no erosion with these crops and run-off is at the minimum. The same is true regarding wheat and other small grains. Corn and potatoes leave the ground more open for erosion, but on account of the sandy loam soil such erosion as occurs is small and localized.

There are frequent prairie fires throughout the sand hills, but the range quickly recovers. Any damage that results from fires and overgrazing is more likely to be due to wind action rather than to erosion.

CONDITION OF FOREST

During the first settlement of this country that occurred from 40 to 50 years ago, a large part of the merchantable timber of the region was cut. The cutting was heavy but not destructive, and many young western yellow pine and eastern red cedar trees are to be found in the river valley. Most of the hardwood growth is from sprouts. Undoubtedly the tramping and browsing of cattle

keeps down the seedlings and some are broken off by cattle. As a whole these forests manage to hold their own despite cutting and grazing. Fires have not been frequent or destructive in the river valley forests.

The county agent of Dawes County estimates that 10 per cent of the river valley in that county is still covered with timber.

The forests on the Pine Ridge are almost exclusively western yellow pine and this is the predominant species along the Niobrara River Valley to about 40 miles east of Valentine. There is considerable eastern red cedar in mixture, also American and slippery elm, green ash, box elder, burr oak, and paper birch. The hardwoods predominate in the eastern part of the river valley and pine gradually drops out.

Protective value of the watershed

(*a*) Soil:	
Sand, 90 per cent, 10,687 square miles, at	100
Loam, 10 per cent, 1,188 square miles, at	75
Total (11,875 square miles) average	97.5
(*b*) Topography:	
Range of altitude	75
Steepness of slope	75
Retention basins	100
Average	83.3
(*c*) Precipitation:	
Distribution	50
Intensity	75
Character of	75
Run-off	100
Average	75
(*d*) Cover:	
Forest, 396 square miles, rating	100
Hay, 1,683 square miles, rating	100
Pasture and crop land, 9,796 square miles, rating	75
Total (1,875 square miles) average	79.3
Average protective value of watershed	83.7

Although this watershed contains a small proportion of timberland, it has a fairly high protective rating due to the water-holding capacity of the large proportion of sandy soil, to the natural reservoirs, the gently rolling country, and the large extent of grass cover.

CRITICAL FOREST AREAS

As just stated, this watershed as a whole has a high protective value. There are very few areas where erosion is serious. The area in forest should not be reduced. The State of Nebraska has a park south of Chadron on a State school section. This might well be enlarged to include a considerable portion of the timbered Pine Ridge.

There is more erosion near the lower course of the river where more loam is encountered than in the upper and middle courses.

The woodland forests in these lower counties should be protected, and the planting of additional forests in areas subject to erosion should be encouraged by the State extension service.

RECOMMENDATIONS

A. *Area to be retained in forest.*—The forested area in this watershed now amounts to about 400 square miles or 3⅓ per cent of the total area. This should be increased to at least 5 per cent, for there is about that proportion of waste land in every farm. This is especially necessary in the eastern part of the drainage. In fact, 10 per cent in forests is none too much for country that is subject to erosion.

The Niobrara division of the Nebraska National Forest can not be termed a critical forest area, as the soil on which it is located is dune sand which has a large absorptive capacity, which is illustrated by the fact that most of the drainage within the forest boundaries is vertical. The surrounding streams, the Niobrara on the north, and the Snake River on the south and east, are fed by springs. The planting of this forest should be continued for the purposes for which it was created—as a demonstration area and a forest for the production of wood products for the surrounding region.

B. *Measures to keep forest lands productive.*—Protection from fire is not a problem in the eastern part of this watershed. In the western part, especially in the sand hills, prairie fires burn over a large amount of range. However, they seldom burn into the river bottoms, and the area of forest destroyed is small. Assistance in the control of insects and tree diseases can usually be given by the State agricultural college and is not a serious problem.

The extension forester should devote more attention to giving advice to the owners of the pine forests in the Pine Ridge so that proper cutting methods may be instituted. The thrifty growing blackjacks are usually cut in their prime. Defective trees are usually removed for fuel, so that the forest contains a stand of young poles. Grazing is usually heavy in these forests, and many young trees are tramped out and cropped or broken off. These forests should be grazed conservatively or they will gradually deteriorate.

More attention should also be paid by the extension forester to the care of the hardwood forests in the eastern part of the State. Many of these forests are deteriorating because of the cropping off of young trees by cattle and the tramping of the ground. The extension service should study grazing methods in the woodland forests and conduct an educational campaign against injurious practices.

4. Forest planting should be pushed with the idea of having at least 5 per cent of the area in each county in forests. A larger proportion than this is needed in the eastern counties.

ADDITIONAL DATA ON RUN-OFF AND FLOOD HISTORY

As stated previously the flow of water in the Niobrara is very constant and there is practically no flood danger. Some damage has been done to property, as well as in eroding river banks, by ice gorges in the late winter. Occasional terrific rainstorms of cloud-burst proportion have caused local damage, especially where the channels of

subdrainages have become blocked from hail or débris. One flood is reported for July, 1903, in the Transactions of the American Society of Civil Engineers, volume 89, page 985 (1926), in an article by C. S. Jarvis, entitled "Flood Flow Chracteristics."

Measurements made near Spencer in Boyd County about 40 miles from the mouth of the river by the United States Geological Survey in 1908, show daily gauge readings varying from 4.1 to 5.6 feet. Most of the variation is due to the shifting course of the river and the formation of sand bars.

The discharge of the river is about 870 second-feet at Valentine and about 1,000 second-feet at the mouth.

The waters of the Niobrara are usually not turbid and the amount of silt carried in suspension is not large. There is considerable shifting and transportation of sand over the rock bottom of the river bed. This resulted in almost the complete siltage of the power reservoir near Valentine, Nebr., within a few years.

PLATTE RIVER

(Areas 59 and 60)

LOCATION AND AREA

Considered only with regard to the extent of the area drained, the Platte is the most important tributary of the Missouri. It is formed by two forks, the North and South Platte, which rise, respectively, in northern and central Colorado and unite a little southwest of the center of Nebraska. The total area of the Platte River drainage is 89,887 square miles, of which the Main Platte including the North Platte comprises 65,832 square miles and the South Platte the remainder.

TOPOGRAPHY

A. *North Platte.*—The North Platte heads in the Continental Divide and the Medicine Bow Range that surrounds North Park. North Park is an open, gently rolling country from 8,000 to 8,500 feet in elevation. The two ranges that surround it rise to elevations of 11,000 to 12,500 feet. From the steep slope of these mountains, numerous small streams descend, unite below into large creeks and flow outward to the center of the basin. Leaving the park, the river continues northward into Wyoming, but near Casper, on the north side of the Casper range, it turns abruptly to the east and southeast, to its point of junction with the South Platte in central Nebraska.

Within North Park the topographic features are diversified, including every degree of roughness from the snow-capped peaks of the Park and Medicine Bow Ranges to level prairie mesas along the lower portion of the stream. The greater part of the region below Saratoga, Wyo., is a rolling, undulating prairie. The mountain streams are of the typical swift, bowlder-strewn type, with an occasional open meadow or willow-covered flat.

Throughout its course in western Nebraska the valley of the North Platte is 10 to 15 miles wide. The present floor, consisting of sediments deposited in a former great valley, is bordered by ter-

races and table-lands scarred by numerous tributaries and arroyas. The stream is broad and shallow, with a flood plain from 1 to 4 miles wide.

The total length of the North Platte from source to mouth is nearly 650 miles. At Fort Steele, Wyo., about 500 miles above its mouth, it is 6,500 feet above sea level; at Fort Laramie it is 4,200 feet, and at North Platte it is 2,800 feet. It is estimated that about one-fourth of the drainage area of this river is in mountains, one-half of it is in hills and rolling land, and one-fourth in plains.

There are many excellent reservoir sites, a few of which have been developed. The most notable is the Pathfinder Reservoir of the United States Reclamation Service. This has a capacity of 1,070,000 acre-feet. Five other reservoirs, having water-storage capacities of 121,680 acre-feet, have been developed. These include the Guernsey Reservoir which is used mainly for equalizing the flow of water through the canals of the project. Undeveloped sites are located on the North Platte River just south of the Wyoming-Colorado State line with a proposed capacity of 2,245,000 acre-feet, the Seminoe Canyon site of 1,055,000 acre-feet and smaller projects on Laramie and Sweetwater Rivers.

Water-Supply Paper No. 469, of the United States Geological Survey, shows an area of 445,645 acres covered by adjudicated ditches and completed ditches not yet adjudicated in the North Platte Basin in Wyoming. The same paper reports 276,000 acres of possible projects in Wyoming and 23,000 acres in North Park. In the Laramie River Basin 183,000 acres are under irrigation with an irrigable area of 329,500 acres.

B. *South Platte.*—The South Platte rises in the mountainous region surrounding the large basin near the center of the State of Colorado, known as South Park. The south branch flows through South Park and joins the north branch at North Platte, Nebr. At the mouth of the South Platte its elevation is 2,800 feet above sea level, and 100 miles above its mouth it is 3,600 feet; at Denver, 288 miles above the mouth, it is 5,170 feet; at South Platte, Colo., about 6,100 feet. Lake George, about 50 miles up the South Fork, is 8,000 feet above sea level, and Cheeseman Reservoir, 23 miles up the South Platte, is 6,850 feet. Many of the small streams that form the South Platte have their origin in the snow banks of the Continental Divide at elevations of 12,000 to 13,000 feet.

The stream gradients are steep, and many of the streams consist of series of cascades and rapids. The lower basin, somewhat scarred and broken along the foothills, gradually merges farther east into the undulating prairies so characteristic of the Great Plains east of the Rocky Mountains. It is estimated that about a fourth of the drainage area of this river is in mountains, although this portion furnishes 75 per cent or more of the total run-off of the basin. About 50 per cent of the drainage area is in hills and rolling land and the remainder is in plains.

Except in the mountain section, the flood plain of the South Platte is very wide. It is cut up by numerous channels and islands containing a dense growth of willows and cottonwoods. It can accommodate an immense amount of water in time of flood. There are many good reservoir sites, but most of the flow, except unusual floods, is stored and used. Cheeseman Lake, which is the main storage for

Denver's water supply, is the largest reservoir, with a maximum capacity of 79,000 acre-feet. Antero Lake in South Park has a storage capacity of 33,000 acre-feet.

Marston Lake, another source of storage for the city of Denver, has a capacity of 19,600 acre-feet. The proposed Eleven Mile Canyon Reservoir, on the South Fork of the South Platte, will have a capacity of 80,000 acre-feet. The Two Forks site at the junction of the north and south branches is large enough for a reservoir of equal capacity, but there are not over 20,000 acre-feet per annum available from remaining flood waters.

A compilation made by Robert Follansbee, of the United States Geological Survey, shows 81 reservoirs having a capacity of 1,000 acre-feet or more and a total capacity of 997,050 acre-feet.

C. *Main Platte.*—From the junction of the North and South Platte Rivers the main stream winds eastward across Nebraska for over 200 miles, uniting with the Missouri at Plattsmouth. Its course lies chiefly through broad level bottom lands, several miles in width, bordered by bluffs varying in height from 50 to 300 or 400 feet. The average fall is about 6 feet per mile.

In the western half of its course the main Platte is a broad shallow stream, flowing in many places as a network of interlacing channels among numerous islands and sand bars, but farther east it is confined between heavily wooded limestone bluffs. It has a tendency to decrease in volume until the Loup is reached. This shrinkage is caused principally by evaporation and irrigation. However, according to reports of the State engineers of Colorado and Nebraska, the flow of the Platte is increasing east of Julesburg and Bridgeport, due, it is believed, to the large amount of irrigation water that finally finds a passage back to the main stream channel.

The Loup River and its branches are the principal tributaries of the Platte below the forks. These rivers flow through the sand-hill region; they are fed principally by springs, and the rate of flow is quite uniform throughout the year.

GEOLOGY AND SOILS

The mountainous section of the Platte River Basin consists of peaks and jagged masses of granite, with sedimentary rocks cut and gashed by stream channels along the foothills. The granites of the region, particularly those at the headwaters of the South Platte, disintegrate quite rapidly and the resulting soil erodes easily, where the forest, brush, or grass cover is scant. Sands and gravels predominate in the mountain sections of the drainage, while loams comprise three-fourths or more of the plains.

The Nebraska portion of the Platte drainage is part of the Great Plains, which is a vast plateau sloping away from the Rocky Mountains. Its deeper lying formations antedate the Rocky Mountain uplift and consist of ancient deposits of Cretaceous and early Tertiary age. Its surface formations, except where they have been removed by erosion, are made up of sediments brought down from the elevated region to the west during and since late Tertiary times and deposited by the streams in thick strata or fanlike aprons.

Erosion and wind action since that period have developed all variations of topography from nearly level plains to rugged buttes and canyons. In Nebraska, wind has been a more active agent of soil formation than water and the sand hills and the loess owe their extensive deposition to this force.

In the eastern part of the State, where the rainfall is greater than in the western, erosion has smoothed the hills, but in the western portion the cutting of the water courses has been more abrupt, and deeply cut valleys, sharp hills, and deep gorges are characteristic features of the landscape.

Throughout the plains section of the river the flood plain proper has a considerable area of silt loam as well as sandy and gravelly soils, part of which is poorly drained. The region adjacent to the Platte throughout Nebraska in the uplands contain a loess soil which is mostly silt, containing some clay and fine sand but classified as a silt loam.

The soil in the mountain sections of the river is composed principally of sandy and gravelly loam on the mesas and of gravelly, sandy, or black loam along the creek bottoms. Much of the mountain region is covered with glacial drift containing numerous bowlders. Gully erosion is common in the mountains, in the narrow valleys, where the cover is inadequate, but erosion is very much localized.

The sand hills occupy about 20,000 square miles of the central and western part of Nebraska, and they are the source of the Loup River water supply.

CLIMATE

The precipitation in the Platte River watershed varies from about 30 inches at its mouth to 16 inches near the west boundary of Nebraska. It is 14 inches in the region surrounding Denver, 12 inches in parts of South Park and along the North Platte in Wyoming, and 20 inches in the higher mountains at the head of the watershed. The largest recorded mountain precipitation, mostly in the form of snow, is 29 inches at Sand Lake, located in the Medicine Bow National Forest, at an elevation of 10,000 feet.

In the plains section of the watershed about 42 per cent of the precipitation occurs in April, May, and June and about 68 per cent of it occurs during the months of April to August, inclusive. In the mountains from 50 to 60 per cent of the precipitation occurs in the form of snow, during the period October 1 to March 31, inclusive. May and June are the flood months, and the high stage is the result primarily of spring rains rather than of melting snows. There are so many storage reservoirs in and adjacent to the mountains that snow water comprises a relatively small percentage of the amount of water that reaches the Missouri River, although this percentage is increasing with the increase in the amount of water that finds its way to the rivers following irrigation. The rapid snow melting occurs in May and June. This water alone is not sufficient usually to cause floods; but when severe rains occur during the period of snow melting floods that do considerable damage, such as that during June, 1921, result.

The winds are high over the plains section of the river basin, and the evaporation is high accordingly. Observations over a series

of five years or more at five stations on the North Platte reclamation project show evaporations ranging from 40 to 52 inches during the growing season.

The mountain sections of this drainage are seldom subjected to the sudden rises in temperature, due to chinook winds, which in some regions cause rapid melting of snow. There are severe winds almost every spring, but these are not primarily hot winds. Snow melting is dependent upon whether the snow occurred early or late in the winter, upon whether the ground was frozen, upon the intensity of the winds, spring temperatures, and the amount of rain.

HISTORICAL DEVELOPMENT

A. In the mountain section of the Platte watershed mining and logging were the first two important uses. For the development of the mines large quantities of mine timbers and lumber were necessary and this resulted in heavy cutting in the forests around which mining centers, as Clear Creek Valley, South Park, the Bowlder region, Encampment, etc. In addition, enormous quantities of timber were cut for railroad ties, especially for the Union Pacific, notably on the Laramie, Encampment, and Medicine Bow Rivers. Severe fires followed or preceded much of this logging and some of these areas have not come back to protective forests 50 to 60 years after they were burned.

With the decline of mining stock raising became the principal business of the mountain areas. The development of the summer-resort business promises to make this one of the leading uses of many sections of the region. The production of railroad ties, lumber, and mine timbers is now being conducted on a sustained yield basis in several places in the national forests of this watershed, but logging has not been developed to capacity in many sections.

The development and use of the land in 15 counties in Colorado and 7 in Wyoming within the Platte watershed are shown by the following tabulation:

State	1920	1925	Farm area, 1925			
			Crop Land	Pasture	Woodland	Total
	Number	*Number*	*Acres*	*Acres*	*Acres*	*Acres*
Colorado	19, 089	19, 838	2, 659, 980	3, 353, 996	325, 668	6, 339, 644
Wyoming	5, 736	5, 979	803, 777	7, 912, 533	114, 102	8, 830, 412
Total	24, 825	25, 817	3, 463, 757	11, 266, 529	439, 770	15, 170, 056

From the foregoing it is evident that the number of farms and the farm acreage is increasing. The character of the land and the nature of its use is indicated by the fact that 77 per cent of the farm acreage reported is used for pasture. This includes 335,776 acres of woodland used for pasture. The area of tilled land can be increased in the North Platte drainage if additional reservoirs are constructed to impound flood waters; but, as shown previously, there is little chance for additional storage in the South Platte. The remaining flood waters will likely be used for municipal purposes by the city of Denver.

The pasture land is all of the short-grass type which is readily erodible if grazed severely.

The woodland area on the 35,817 farms averages 17 acres per farm. It represents about 3 per cent of the total area, but most of these woodlands are in the mountain counties. Some of the plains counties report less than 100 acres of timberland. Three-fourths of this woodland is used for pasturage.

A cross section of land utilization for 7 counties in the western part of Nebraska, 8 in the central, and 8 in the eastern, shows the following:

Farm acreage, 1925

Group	Crop lands	Pasture land	Woodland		Total farm land
	Acres	*Acres*	*Acres*	*Per cent*	*Acres*
Western	1,237,639	2,137,982	19,967	0.5	3,538,742
Central	2,460,970	1,583,342	51,890	1	4,231,947
Eastern	1,678,379	332,986	90,090	4	2,210,909
Total	5,376,988	4,054,310	161,947	1.6	9,981,598

NOTE.—Discrepancy between sum of acreages and the total caused by the fact that land classed as "Other" in farm census reports was not included in the above tabulation, except in the total.

The increase in the amount of crop land and of woodland from the west to the east boundary of the State is shown in the above tabulation. Short grasses predominate in the western part of the State and in the blue buffalo and grama-grass pastures of the eastern counties. The sand hills are largely covered with tall grasses.

B. *Condition of forests.*—Within the Platte River watershed there are 2,204,380 acres of national forests in Colorado and 716,236 in Wyoming. Also there are about 169,000 acres in the Rocky Mountain National Park. Other forested land in the public domain in Colorado and Wyoming amounts to about 300,000 acres, including about 20,000 in Independence Mountain country on the east side of the Hayden, 35,000 acres in the Elk and Jelm Mountain units in the Medicine Bow, and about 200,000 acres in the Laramie Peak country in T. 25 to 30 N., R. 71 to 74 W. This makes a total of about 3,390,000 acres of forest land in Government ownership in this watershed. In addition there were reported in 1925 agricultural census, 439,770 acres of woodlands by farm owners in the 22 counties in Colorado and Wyoming in the Platte drainage, making a total of 3,829,000 acres of forest or potential forest land in this watershed. About 70 per cent of the park and national forest portion of the unit is covered with tree growth. The remainder is grassland, alpine meadows, sagebrush, or barren (above timber line).

Within the national forests in the Platte drainage, there are 134,746 acres of denuded land. Most of this is the result of fires in the early development of the region. The area burned over in the national forests of Colorado and Wyoming since fire protection has been well organized, is relatively small. For instance, out of a total area of 829,414 acres in the Colorado forest only 708 acres have been burned during the past 18 years. The area burned on the Medicine Bow during the same period totals 2,345 acres of a total area of 552,174 acres. For these two forests, which are representative of all

within the Platte watershed, 0.2 per cent of the total area has been burned in 18 years.

In the western Nebraska portion of the Platte, there is considerable irrigated land in the river valleys and adjacent land. Stock raising is the principal industry. The area in farm land increases steadily to the east and from the junction of the North and South Platte to Missouri is one of the richest farming regions in the Central West. In the central and eastern part there are more planted as well as natural groves.

CONDITION OF LANDS OTHER THAN FOREST

A. *Improved lands.*—The principal crops in the Platte drainage in Colorado are hay, including wild and tame hay and alfalfa, sugar beets, potatoes, wheat, corn, fruit, and produce. In Wyoming, hay, wheat, and corn are the chief crops. Most of the cultivated land is irrigated and, according to information furnished by the county agents in this region, the generally level character of the land, the nature of the crops raised, and the method of cultivating are such that there is very little erosion. Occasionally in fields with some slope where crops are planted in rows, there is some erosion where care is not used in irrigating.

In northeastern Colorado, southeastern Wyoming, western and central Nebraska, county agents state there is more soil wastage from high winds during the winter and early spring than from water erosion.

The extension service of the several States is advocating methods of cultivation to reduce wind erosion, such as the use of a shovel implement to leave a broken surface that breaks the progress of the wind and makes depression for water and snow storage. Also they advocate leaving as much residue as possible from the crops to serve as a mulch during the winter.

There is considerable erosion in the loam soils of eastern Nebraska and many fields have been abandoned because of deep gullies. Some farmers have resorted to the use of brush or soil dams to overcome this type of erosion, but the average farmer is doing nothing and erosion is increasing.

B. *Unimproved lands.*—Supervisor Blackhall, of the Hayden Forest, who has been familiar with range conditions on the North Platte drainage from the headwaters to Casper for 30 years, reports the following for the range on the public domain:

> Wherever there is unfenced water the range will be found to be seriously overgrazed. A large portion of the range, however, is protected by lack of water, and since this range may be grazed only when there is snow on the ground the plants usually grow to maturity before they are grazed and are not seriously affected by overgrazing during the winter season. Sheepmen tell me that the range on the desert is as good as it was 30 years ago. The amount of precipitation each year determines the amount of forage there will be on the ground.

Supervisor Hilton, of the Medicine Bow Forest, states that stockmen consider the range about the same now as 25 years ago, conditions varying annually according to the rainfall. There is only a small amount of livestock in the region now as compared to 1920 and the range is having ample opportunity to recover. Overgrazing and erosion on the range is limited to small isolated areas.

Supervisor Rist, of the Leadville Forest, reports that there are 75,000 acres of private land in South Park on which the forage is less than it was 25 years ago, due to heavy and early grazing in the spring.

Ranger F. Parrett, of the South Platte district of the Pike Forest, reports that there are 35,000 acres of private land along the North Fork of the South Platte, extending from Pine to the village of South Platte and north to the heads of the subdrainage, on which the forage cover is decreasing and erosion is resulting. The timber was cut in the eighties and the area has been overgrazed. This is the only area on this subunit where erosion is having any considerable influence. On the South Fork of the South Platte a heavy cutting of timber from 1880 to 1890 resulted in considerable erosion. This is now decreasing as a result of the considerable growth of young trees as well as the institution of regulated grazing on the national-forest ranges.

Supervisor W. R. Kreutzer, of the Colorado Forest, reports there is considerable overgrazing in the foothill country adjacent to the Colorado Forest. These areas include the east side of the Laramie River, containing 25,000 acres, also the foothills along the west margin of the Medicine Bow range in Jackson County, extending from the Colorado Forest to the Canadian River, comprising 34,000 acres. There is some overgrazing and slight erosion on 6,000 acres located along the Big Laramie River. In addition, the foothills in the Cache la Poudre River show overgrazing on about 50,000 acres. In some of the foothill country western yellow-pine reproduction is gradually restoring a cover but erosion is taking place in some areas.

Supervisor Leighou, of the Arapaho Forest, states that 90 per cent of the area adjacent to the North Platte portion of the Arapaho was overgrazed prior to 1921. The depression in the stock industry about that time resulted in the reduction in the number of cattle in the country and was the salvation of the range. There is very little erosion in this country and the few areas that are eroded show the gully type.

Ranger Ray Bradshaw, of the Lake George division of the Pike Forest, reports that there is slight erosion in widely scattered areas in the South Platte portion of the Pike Forest and adjacent territory. This occurs wherever the natural soil cover has been disturbed by man, such as old roads, trails, and cultivated fields. Approximately 1 per cent of the South Park country shows erosion in the form of gullying and silting of streams.

The same condition is true regarding the private lands in this region. Overgrazing and consequent erosion is confined to small areas. The rainfall in the western portion of the Platte drainage is small and the vegetation is scant. Heavy grazing soon causes damage. Frequently the rainfall is in the form of cloudbursts, with resulting erosion, usually of the gullying type.

A plot fenced and protected against stock for eight years in the South Platte drainage near the town of South Platte, Colo., shows but little increase in density of volume of vegetation and very little difference in erosion between conditions on the plot and the outside range. However, the unfenced areas have not been heavily grazed during this period. Heavy grazing in the characteristic disinte-

grated pasture lands of the South Platte region is responsible for some deep gullying in scattered localities. Sheet erosion is not noticeable in the range lands of the region.

CONDITION OF THE FOREST

The Medicine Bow Forest contains a larger proportion of timbered lands than the average. Seventy per cent of this forest is timbered. On the Leadville, counting the conifer and aspen types, 62 per cent of the total area is timbered, and if this brush type (including willows) is added, 67 per cent may be considered as having a forest cover. The North Fork portions of the Arapaho and Routt are about 85 per cent timbered, aspen and reproduction stands being included.

The lodgepole pine type contains the largest proportion of merchantable timber, with 68 per cent to its credit. The spruce fir is next, with 28 per cent, and western yellow pine-limber pine constitute the remaining merchantable timber, with 3.5 per cent of the total. A brief description of the types follows:

(1) *Spruce-fir type.*—The spruce-fir type is the most important watershed-protection type in the region. It occupies the higher elevations where the snows are greatest and usually occurs in dense stands, so that evaporation and snow melting are at a minimum. The forest floor in this type contains a large quantity of down material, humus, duff, and moss. Its water-storing capacity is high. In the Medicine Bow Forest it occupies only about 7 per cent of the total area of the forest, whereas on the Routt it occupies 23 per cent and on the Leadville 31 per cent of the area. Considering only the timbered area, the Engelmann spruce type on the Leadville comprises half of the total. Within the Colorado section of the Platte drainage the spruce and fir type has a total stand of 1,045,748,000 board feet, or 36 per cent of the total stand of merchantable timber, while in Wyoming this type comprises 24 per cent of the stand.

(2) *Lodgepole-pine type.*—The lodgepole-pine type is found at relatively high elevations in this region and ranks next in value to spruce-fir for watershed purposes. It also occurs in dense stands, this being especially true of the sapling and young pole stands. Average stands in this type contain large amounts of down timber and a fairly deep layer of humus and forest litter. For these reasons its snow-holding and water-storing capacities rank high. In the Colorado forests within this drainage 55 per cent of the merchantable timber is lodgepole pine, whereas 75 per cent of the timber in the Wyoming forests is lodgepole. Sixty per cent of the total area of the Medicine Bow Forest is occupied by this type, while the Routt has but 37 per cent and the Leadville only 12 per cent lodgepole pine.

(3) *Western yellow and limber pine.*—Western yellow and limber pine occur in smaller areas and volumes in both groups of national forests, 8 per cent of the stand in Colorado consisting of these two species, while in Wyoming the ratio is less than 1 per cent. Western yellow pine occurs at the lower elevations and limber pine is found on the ridges and wind-swept sites. Neither type has much watershed value, excepting that the litter and humus retards run-off

appreciably. Snow does not remain long in the yellow or limber pine types.

(4) *Aspen-willow-cottonwood type.*—Aspen, cottonwood, and willows are the principal broadleaf trees in the region. Aspen comes in on many situations following fires and under its protective cover spruces and firs get a start and eventually crowd out the nurse tree. The annual supply of leaves builds up a deep humus layer so that this type has a fairly high watershed value, especially in retarding run-off. Since the trees are bare in winter this type does not retard snow melting. It comprises about 4 per cent of the total area of the Medicine Bow Forest and about 15 per cent of the area of the Routt.

Areas containing mixed willows and wet meadows are found in all the national forests. They have a high watershed value, since this type is the natural home of the beaver and their dams hold back enormous quantites of water and retard run-off. The acreage is not large since it usually occurs in relatively narrow strips. However, on the Medicine Bow, for example, this type contains 10,570 acres or about 2 per cent of the total area of the forest.

After leaving the mountain section the only natural tree growth is found in the stream valleys and consists of cottonwoods and willows. This is true until the eastern portion of the Platte River is reached and here more species of hardwood are found in the valleys and on other favorable situations. The planting of farm windbreaks and wood lots is being pushed by the State extension services of Colorado, Wyoming, and Nebraska, but such wood lots will have no appreciable effect on run-off. It is necessary to cultivate these groves for a good many years to prevent vegetation from killing out the trees. Their value is mainly in providing wind protection and fuel to the farmer.

This is not true, however, in the eastern half of Nebraska, where mixed hardwood forests should be planted on lands that are eroding. There are many areas that can no longer be farmed because of gullies and these should soon be planted.

(A) *Effect of lumbering, fires, grazing.*—The spruce-fir type has been logged around many of the old mining camps in the region, including Fairplay, Georgetown, Ward, and others. The logging in itself, although heavy, would not have destroyed the value of these forests, but almost invariably fires followed logging. In some places aspen came in following the fires, but on many of the spruce burns there is no reproduction and the run-off is rapid, although the quantity of material on the ground usually prevents erosion. Wherever fires did not occur after cutting there has been as a whole good reproduction, following the early day cuttings. A good bit of this cutting was on patented land, but there was also considerable trespass cutting on Government land.

The characteristic spruce burn contains large quantities of standing dead and down timber, and there is little or no reproduction or aspen cover. Some of these burns have an abundant grass and weed cover, but others, such as those at the headwaters of the South Platte in South Park, have a hard-baked soil from which the run-off is much more rapid and the evaporation and snow melting is much greater than in the tree-covered areas of this type.

The Glendevy burn at the headwaters of the Laramie River is a result of the fires that followed the early day cutting for railroad ties for the Union Pacific. This is, however, an example of a burn that after many years secured a satisfactory stocking of young reproduction.

Early day cuttings in the lodgepole-pine type were never so heavy as to be detrimental, provided fires were kept out. This is illustrated by the heavy cuttings on the Carbon Timber Co. lands in the Medicine Bow Forest and the Hayden Forest, which now contain dense stands of young reproduction. There have been severe burns in this type, as on the Medicine Bow and Routt, that have not come in satisfactorily, but the greater portion of the type is satisfactorily stocked.

Heavy logging and fires in the western yellow pine and Douglas fir type have been detrimental and have produced some of the denuded areas that are to be found in the South Platte drainage on the Pike Forest. Fires in the western yellow-pine type usually leave a more open and desolate country, which requires a longer period to return to forest conditions. Less material is left on the ground, and partly because of the absence of litter and down material and partly due to the disintegrated granite soil, there is considerable gullying in places.

With proper range management and supervision there is no need for overgrazing and consequent soil damage and, as a rule, overgrazing national-forest areas is not a factor in the satisfactory stocking of burns and cut-over areas, nor can very much soil erosion damage be atributed to it. There are occasional instances of overgrazing on private land within the region.

Grazing of the hardwood forests in the eastern part of the Platte watershed is detrimental. This is evidenced by the absence of reproduction and by the gradual deterioration and opening up of the natural and planted wood lots in this region. There is no erosion in these hardwood forests, but they are gradually ceasing to be of value with the opening of the stand.

Protective value of watershed

	Square miles	Rating	Range, steepness, etc.	Rating
(*a*) Soils:				
Sands and gravels—				
Colorado	20,995			
One-half Wyoming	13,345			
One-fourth Nebraska	21,100			
Total	55,440	100		
Loams—				
One-half Wyoming	13,346			
One-fourth Nebraska	10,551			
Total	23,897	75		
Clay, one-fourth Nebraska	10,550	50		
Total	89,887			
Average rating		87.4		

Protective value of watershed—Continued

	Square miles	Rating	Range, steepness, etc.	Rating
(*b*) Topography:				
One-fourth Colorado	5, 248		Range of altitude	50
One-half Wyoming	13, 346		Steepness of slope	50
			Retention basin	100
Total	18, 594	66⅔		
Three-fourths Colorado	15, 746		Range of altitude	100
One-half Wyoming	13, 346		Steepness of slope	100
Nebraska	42, 201		Retention basin	100
Total	71, 293	100		
Grand total	89, 887			
Average rating		93		
(*c*) Precipitation:				
			Distribution	75
One-fourth Colorado	5, 248		Intensity	50
One-half Wyoming	13, 346		Character of	100
			Snow melting and run-off	50
Total	18, 594	75		
Three-fourths Colorado	15, 746		Distribution	50
One-half Wyoming	13, 346		Intensity	75
One-half Nebraska	21, 100		Character of	75
			Snow melting and run-off	100
Total	50, 192	68¾		
			Distribution	50
One-half Nebraska	21, 101		Intensity	75
			Character of	75
			Snow melting and run-off	100
Grand total	89, 887			
Average rating		71. 5		
(*d*) Cover:				
Forest, Colorado and Wyoming	5, 948	100		
Pasture, Colorado and Wyoming	36, 357	75		
Crop land, Colorado and Wyoming.	5, 381	81		
50 per cent hay, 100.				
25 per cent grains, 75.				
25 per cent corn, etc., 50.				
Total	47, 686			
Nebraska:				
Forest cover (1 per cent)	549	100		
Pasture (40 per cent)	16, 880	75		
Crop land (49 per cent)	24, 772	69		
Total	42, 201			
One-fourth hay, at 100. 0				
One-fourth grain, at 75. 0				
One-half corn, at 50. 0				
Average rating 75. 5				
Total	89, 887			

SUMMARY

	Rating
Soils	87. 4
Topography	93. 0
Precipitation	71. 5
Cover	75. 5
Protective rating of the Platte watershed	81. 8

The sands, gravels, and sandy loam soils of this watershed give it a fairly high protective rating from the standpoint of soils. The fairly level nature of considerable of the watershed more than offsets the steepness of the mountain portions and produces a high rating

from the standpoint of physiography. The distribution of precipitation largely during the spring and early summer gives a low rating for precipitation. The relatively small area of forest land and the large area of plowed fields gives a low rating for cover.

The final value shows the watershed to have slightly better than a medium protective value.

The high rating given to the forest cover and the disintegrated granite soil of the mountain section of the watershed were checked by records made during the flood of June, 1921. The peak of the inflow into Lake Cheeseman did not occur until four days after the heavy rainfall had occurred. This is confirmed by the stream-flow measurements made by the United States Geological Survey at the junction of the north and south forks of the South Platte.

CRITICAL FOREST AREAS

The national forests and parks and the forests in the public domain, by reason of their cover of trees, brush, and grass, which retard the melting of snow and the run-off of water, exert a markedly beneficial influence. Without this forest cover the mountains would exert a very detrimental influence upon the Mississippi watershed. Accordingly, all national forests and parks and public domain forests, as shown on the map, are considered critical forest areas. Their condition is described under "Condition of Forest."

The only portions of these forests that exert a neutral influence are the areas above timberline. Here is deposited an immense amount of snowfall. Trees can not grow at this altitude, and the melting of snow is influenced by winds and the prevailing temperatures.

For the Platte drainage, the most important consideration is to plant 135,000 acres of denuded land in the national forests at the headwaters of the stream. These will help the present forests to hold back flood waters, to retard the melting of snow, to reduce evaporation. Most of these areas are only a few thousand acres in size, and they are scattered over 3,000,000 acres of national forest lands, so that each in itself exerts only a small influence and that is felt mainly locally. In the aggregate, however, the lack of cover on these areas increases the amount of erosion and causes more rapid flowage of water.

The policy with regard to such areas will be to increase planting as rapidly as available funds permit. Most of these burns have more or less down material, scattered stands of aspen, but not sufficient in any case to form an effective cover. A cover of conifers is necessary to make these good water protection forests. At present their influence is negative compared to the beneficial influence of the surrounding coniferous forests.

In the eastern part of the Platte River drainage, on the main stream, as well as on the tributaries, there are numerous places where erosion is causing so much gullying as to ruin farms. Clayton Watkins, extension forester for Nebraska, says:

> There are several thousand acres of badly eroded land along these streams, especially in eastern Nebraska, that are rapidly growing worse, and they are not only encouraging rapid run-off but are ruining valuable farms. Investigations show where farms have been completely divided by gullies within the last 15 years. These eroded areas are so scattered, in fact, they are generally parts

of individual farms, that it would seem next to impossible to join them in a flood-control project except by working through the landowner. Since, for the most part, these areas are unproductive, even though they are taxed as agricultural land, the owner should welcome the opportunity of getting assistance in controlling a very disastrous enemy. This would undoubtedly be a slow process, but with demonstration work and an intensive educational campaign it seems that some good might result.

A place between Lincoln and Omaha, on the D. L. D. Highway, and the Burlington Railroad is called to mind, where water erosion is taking its yearly toll. This could be used as a demonstration flood-control project by a little terracing and a lot of planting. Then by the use of a suitable signboard, the attention of many people would be called to the wok, and if successful, serve as an educational medium. This particular location is mentioned only as an example, and if advisable could be carried out in many other places.

Some very productive farm land is being "manufactured" along the Mississippi River by "river-bank retards," installed by Woods Bros. Construction Co., of this place, with topsoil from Nebraska, Iowa, Dakota, and Minnesota farms, which is transported by flood waters. This, of course, is at the expense of the farmer whose land is subject to rapid run-off of spring and summer rains.

A situation such as this will have to be met largely by encouraging the planting of trees on individual farms. Cooperation under Section IV, of the Clarke-McNary law is just under way in Nebraska, Colorado, and Wyoming. It should be pushed by further aid, where necessary, to see that cheap trees are available for the farmer who should plant. If possible, a survey of badly eroded areas that should be planted should be made and a campaign started by extension foresters to induce the owner of such lands to plant. In very serious cases special help should be given the farmer, and, if the situation is then too bad, such areas should be purchased by the State or counties as public forests.

Extension Forester C. A. Lee, of Colorado, reports the following on the condition of the forests in the South Platte watershed:

The South Platte drains a region of porous soils containing much sand and fine gravel. These soils have an extremely low humus content. The cumulative effects of erosion by water, therefore, are (*a*) the cutting action upon banks and channels; (*b*) the shifting of currents to new courses; and (*c*) the gradual building up of the river bed at intervals only to be cut again during the next flood stage.

There is little doubt that the bottom lands of the South Platte River are more heavily timbered to-day than prior to the coming of the white man. This fact is attributed to three reasons: (1) Reduction in fires; (2) reduction in vast herds of game animals that browsed upon reproduction; (3) diversion of flood waters to irrigation reservoirs and irrigation canals.

The prevention of wind erosion is of the utmost importance within the South Platte region. Wind erosion literally moves the topsoil of the entire plains region each year. Cultural practices used in agriculture assist in prevention. However, the planting of evergreen windbreaks has proved the most effective manner of reducing the direct forces of the wind as well as serving as a soil trap for settling incoming sands, thus protecting the fields.

Prof. W. J. Morrill, State forester of Colorado, says:

The farm wood lots, chiefly in eastern Colorado, are either of natural origin, mainly cottonwoods, along the river banks, or artificially created wood lots or groves. Due to splendid natural reproduction by seed and sprouts, the cottonwood wood lots on the stream banks are at least holding their own, and may even be expanding, as is claimed by old people familiar with early pioneer history. The planted groves are prized too highly for shade, beauty, and as protection from the wind to be cut severely. Such wood lots are far too few to have any influence on stream flow. With continued agricultural development those groves, and especially shelter belts, will become more common.

No State forest is particularly needed on the South Platte watershed. The city of Denver owns and protects against fire and cutting 10,239 acres of forest land as mountain parks on this watershed. This precludes the advisability of the State owning a forest there. The city of Boulder owns approximately six sections, or 3,840 acres, of forest within the area under discussion. The counties own no forest land other than a small amount of forest land which has reverted in lieu of unpaid taxes, but very unsatisfactory conditions obtain from the fact that the counties in Colorado can not give or hold a clear title to this land.

It is not feasible to afforest large areas in the plains region, neither is this needed for flood control, which is largely already successfully handled by the irrigation reservoirs anxious to use flood water for impounding. While flood water, to some extent, still escapes from the State, the increasing value of irrigation water will impel the irrigation companies soon to take measures to save and impound the relatively small amount which now escapes.

In summation: Our forests are in good condition from the viewpoint of cover; nothing of importance need be done in the forestry line beyond protecting the domestic water supply of our larger cities. This is progressing, perhaps, too slowly. The nature of the ownership, largely public ownership, insures proper protection of the forests from fire and overcutting. Extensive and intensive irrigation interests have seen to the matter of impounding flood water to a degree unequaled in the Mississippi watershed, and this development is proceeding to the point of almost absolute guaranty that no guilty flood water shall pass eastern confines of Colorado.

The level, thirsty plains of the eastern portion of the State will never let a great amount of water find its way into the rivers. Besides, the precipitation here is always less than would cause floods. We have no flood problem, in the sense that the Mississippi River is adversely affected, because of conditions in Colorado.

We have local washouts. Here and there in the mountains some erosion is occurring. But eastern-slope water is too valuable to permit any considerable amount of it, even flood water, to pass out of the State until it has been used to irrigate crops. Eventually much of this water slowly finds its way again to the rivers, but it is long after flood conditions have prevailed in the Missouri or the lower Arkansas Rivers.

CRITICAL RANGE AREAS

The area in the public domain within the North Platte watershed in Wyoming is considered a critical range area. At present, conditions are not serious, as is brought out in the comments of Supervisors Blackhall and Hilton, on page 576. A boom in the stock industry would soon cause an overstocking of this range and resulting erosion. This grazing land should be placed under Federal supervision or regulation, somewhat similar to the grazing administration on the national forests.

RECOMMENDATIONS

A. *Area to be retained in forest.*—The area in forests within the Colorado and Wyoming portions of the Platte drainage, including the national forests and park areas, that portion of the public domain known to be in forest, and the woodlands, as given in the 1925 farm-census reports, amount to 3,829,000 acres, or 12 per cent of the total area within these counties. It is true that portions of the national forests and parks are grassland or above timber line, but they are under public control and will always be used conservatively. Grasslands having a good cover exert a beneficial influence in stream control.

It is recommended that steps be taken to have the following public-domain areas added to the national forests:

Unit	Forest	Net area
		Acres
Independence Mountain	Hayden	20,000
Jelm Mountain	Medicine Bow	22,000
Elk Mountain	do	10,000
Laramie Peak, Cold Spring	do	200,000
Bull Mountain, T. 11 and 12 N., R. 75, 76 W	Colorado	7,390
Total		259,390

These areas should be in national forests because (1) they are mainly timbered and should be under public control rather than subject to homestead entry and unregulated cutting; (2) they are at the headwaters of important irrigation and watershed protection streams and contribute in a small way to the Mississippi flood waters.

The acquisition of scattered private timberland holdings within the national forests through land exchange will be continued. Most of the lands that are now being acquired under exchange have been cut over and are used for grazing. They are more valuable for forests and should be in public control. National forest receipts up to 65 per cent of the total should be made available for this purpose until all desirable areas are acquired.

Consolidation of the State school lands into a State forest and the proper management of the isolated school sections in the mountain districts should be worked out.

Where the nature of the land and climatic conditions are such that a family can not make a living, submarginal land of this type in the national forests and public domain should not be listed. Cultivation of mountain meadows results in the destruction of soil cover; erosion eventually starts and these fields become markedly detrimental. The cultivated lands in the mountain valleys are the source of most of the erosion in the South Park region. These cultivated areas are mostly in the form of narrow strips along the valleys where erosion and the cutting of stream banks is destroying the value of the land. Such lands should be in forest or sod.

B. *Measures necessary to keep forest land productive.*—1. The present effective fire-protection system in the national forests and parks should be continued and improved, as prevention, detection, suppression, and cooperation methods are studied and improved. The record of the past 18 years in national forest protection in Colorado shows a loss of one-fifth of 1 per cent of the total area. This is not mentioned boastfully, for every forest officer realizes that it should be less and can be reduced despite greater use of the forests.

If the public domain forests are not added to the national forests, arrangements for their protection should be made by the Department of the Interior as the greatest fire loss in recent years has occurred on these forests.

2. Immediate steps should be taken to control all insect infestations and forest-tree diseases in their incipiency. The fire control or similar fund should be made available for this purpose so that valuable time will not be lost in waiting for special legislation and appropriation. The necessity for prompt action in private forests should also be impressed upon the public by the State extension forester.

3. Present methods of cutting and forest management should be continued and improved as experience and research shows the way. State extension foresters should also endeavor to have proper forestry methods accepted in the management of private timberlands.

Funds should be provided to place the Central Rocky Mountain Forest Experiment Station on a basis so that the silvicultural problems connected with the management of 20,000,000 acres of National, State, and private forests in this and adjacent watersheds can be adequately studied.

4. (*a*) Increased funds should be provided to plant a larger area of denuded lands on the national forests annually so that the entire area, amounting to 135,000 acres, may be planted within 25 years.

(*b*) The cooperation of every community dependent upon the national forests for water supply should be enlisted, not only to support the Forest Service in the planting of denuded national forest lands, but also to plant city and private lands of strategic importance in watershed protection. Arrangements should be made to raise trees at cost in Forest Service nurseries for States and municipalities who wish to plant on their own lands. The scope of the Clarke-McNary law should also be widened so that trees can be made available for other than farm wood-lot planting, such as the lands of lumber or coal companies or other corporations.

(*c*) Cooperation with the States in the distribution of cheap planting stock for farm wood lot and windbreak planting should be made more effective (1) by seeing that none but first-class stock of reliable species is sent out, and (2) by demonstrating proper methods of planting and care of plantations.

5. The State extension services should be urged to incorporate in their farm management program the demonstration of proper grazing methods in pastures along the lines worked out in the national forests and at agricultural experiment stations. The study of the effect of grazing upon forest reproduction should be continued in the national forests and by the States in farm wood lots.

ADDITIONAL DATA ON RUN-OFF AND FLOOD HISTORY

The following data are given for floods of which there is authentic record in the Platte River Basin:

Subdrainage	Date	Drainage area (square miles)	Maximum run-off, second feet per square mile
South Boulder	August, 1905	125	9
Crow Creek	May, 1904	251	37
Big Thompson	July, 1919	274	29
Laramie River		435	10
Cherry Creek	June, 1923	87	195
Do	July, 1912	445	25
Cache la Poudre	May, 1904	532	38
Do		1,060	5.3
South Platte	June, 1921	3,840	2.3
North Loup	June, 1899	4,020	19.0
North Platte, Wyo		14,828	1.5
Do	June, 1908	16,200	[1] 1.9
North Platte, Nebr		24,800	8.98
Platte (Columbus, Nebr.)	May, 1905	56,900	.83

[1] Highest in 20 years.

It is very difficult to secure accurate records of floods and the foregoing list, while inadequate for the purpose desired, is taken from what is considered by engineers to be the most complete tabulation of floods on record. All of the floods listed, except the last four, are probably of the cloudburst type, which are due to intense rains of short duration covering well-defined small areas. Floods of this type, while very destructive in the locality where they occur, make only a small impression on the main Platte or Missouri River drainage. At the usual time of their occurrence there is as a rule only a small amount of water in the stream bed. The channels in the plains section are wide and sandy and absorb large quantities of water. Probably 75 per cent to 90 per cent of the flood flow is due to the precipitation of flood storms.

Because of the sandy nature of the channel and of the soil through which the branches of the Platte flow, these streams are remarkably free from sediment in suspension, except at time of heavy storms. During floods the turbidity of these streams is low, as compared to the main Platte or Missouri in flood stage.

Because of the cloudburst character of the storms above the main Platte there is considerable erosion from unprotected hillsides and fields, and the movement of sand, gravel, and other detritus in the stream channels is enormous. The main Platte has a fall of only 6 feet per mile and the movement of sediment is not so marked although there is a large amount of soil in suspension.

Extreme discharges have been recorded in 1921 on the North Platte, at North Gate, Colo.; in 1909 at Saratoga, Wyo.; in 1917, at Pathfinder, Wyo.; in 1893, at Douglas, Wyo.; in 1899 at Orin Junction, Wyo.; in 1908, at Guernsey, Wyo.; and in 1917 at Whalen, Wyo. This indicates that flood conditions are not apt to prevail along the entire length of the stream at the same time.

Studies made by Robert Follansbee and reported in Water-Supply Paper 500–C, Characteristics of Run-off in the Rocky Mountain Region, United States Geological Survey, indicate that heavier precipitation, mostly in the form of snow, occurs at higher elevations throughout this region than those reported under Caption IV, Climate. The amount of precipitation is influenced by the geographical location of high mountain masses as well as by altitude. Precipitation charts have been prepared by Mr. Follansbee, based upon the distribution over the watersheds of the measured discharges of mountain streams and upon snow-scale readings. Allowances have been made for losses by unmeasured percolations of waters and upon evaporation. The resulting figures show belts on the west side of North Park, in the Sierra Madre and Medicine Bow Mountains, where the annual precipitation amounts to 50 inches and larger belts at lower elevations averaging 40 inches.

These figures are much larger than any recorded measurements of Weather Bureau stations, which are mostly located at lower elevations. They emphasize the importance of the mountain portions of the Platte watershed and especially the need for forest cover to retard the melting of the heavy snowfall and run-off.

REFERENCES

1. The section on topography of the mountain section is taken largely from Water-Supply Paper No. 469 of the United States Geological Survey.

2. Section on geology and soils taken largely from Water-Supply Paper No. 469 of the United States Geological Survey, and from the Soil Survey Report of Western Nebraska of the Bureau of Soils.

3. Information on climate secured largely from United States Weather Bureau publications.

4. From article by Ivan E. Houk, Evaporation on United States Reclamation Projects, January, 1926, number of the transactions of the American Society of Civil Engineers.

5. From Department of Commerce bulletins, giving census of agriculture for Colorado and Wyoming in 1925.

6. Page 48 of Nebraska Resources and Industries, Bulletin 14, of the Nebraska Conservation and Soil Survey Department.

7. Article by F. R. Johnson, in December, 1922, issue of Water Resources, entitled "The Influence of the Forest in Retarding Runoff," etc.

8. Taken from paper No. 1589 of the transactions of the American Society of Civil Engineers, Flood Flow Characteristics, by C. S. Jarvis.

BIG SIOUX

(Area 61)

LOCATION AND AREA

The Big Sioux River drainage area includes (1) a comparatively narrow strip of territory, varying from less than 1 mile to about 42 miles wide, along the eastern side of South Dakota, extending from the extreme southeastern corner of the State northward for a distance of about 200 miles, covering an area of 5,172 square miles within South Dakota; (2) a triangular-shaped area of 1,353 square miles in the extreme northwest part of Iowa, lying mostly northward from Sioux City; and (3) a triangular-shaped area of 1,687 square miles in the extreme southwestern corner of Minnesota, which area extends eastward along the south boundary of Minnesota about 40 miles and northward along its west boundary about 66 miles. The total area within the watershed is 8,212 square miles.

TOPOGRAPHY

In general this region may be classed as a plains area, having a general southerly slope. Along the southern part of this drainage the hills and bluffs are comparatively high, rising 100 to 300 feet above the river valley. The elevation of the lowest part near Sioux City is 1,100 feet. From this point there is a gradual rise to an elevation of around 1,800 feet in the northern part. The Sioux River, irrespective of the falls and rapids near Sioux Falls, has a gradient of more than 2 feet per mile. That portion of the area in Iowa and Minnesota, as well as in the northern part within South

Dakota, is a level to rolling upland prairie. The entire area is cut by numerous streams and water courses, some of which are narrow, others broad and flat.

In portions of the watershed the drainage is rather incomplete and many lakes are scattered over the area. The Big Sioux Valley lies between glacial moraines on the east and west. In Brookings County, S. Dak., which is a fairly typical midway cross section of the area, the drainage consists of rolling and level upland prairie cut by numerous stream valleys.

GEOLOGY AND SOILS

(A) *Geological formations.*—The surface formations belong to the glacial period. There are a few outcrops of basal rock in portions of the Big Sioux Valley. These outcrops consist chiefly of Sioux quartzite belonging to the Algonkian formation. Practically the whole area is covered by glacial drift of varying depths, the result of one or more glacial invasions. The material deposited in this manner is a mixture of clay, sand, pebbles, and bowlders. Overlying the glacial deposits is a fine porous clay, called "loess." This formation is distinguished from the glacial deposits by its lack of pebbles and bowlders. Both this loess and glacial material are subject to erosion much more readily than are the underlying formations.

(B) *Soils.*—The soil of this region is quite uniformly a loam derived from the glacial deposits and the loess as subsoils. The valley floor of the main rivers is filled with sands and gravels overlain by an alluvial soil. The bottom lands of the Big Sioux River above the Missouri have an average width of about 2 miles. The soils in this region are comparatively easily eroded, as is indicated by the increasing depth of the river valleys as they near the Missouri River Valley.

That portion of the Iowa glacial sheet exposed in this area shows the effect of greater erosion and longer weathering and gives rise to soils containing more sand than those of the Wisconsin glacial sheet. The soils, as a rule, become more heavy and loamy as the moraines on each side of the Sioux Valley are approached. The most serious erosion which has occurred is the ruining of farm land due to caving of river banks which is not, however, excessive. Very little waste land is found in this unit except river wash and dune sand.

CLIMATE

For the general region eastern South Dakota and northwestern Iowa, the average annual precipitation is about 25 inches. The greater portion of this falls within the crop-growing season, more than three-fourths of the annual total being received within the six months, April to September, inclusive. The greatest monthly precipitation usually occurs in June, closely followed by May and July. The greatest annual averages are in the southern counties east of the Missouri and in northwest Iowa.

The average annual rainfall of the South Dakota portion of this area is sufficient for the production of good crops, but the variability of the precipitation during the growing season is often a serious matter.

In an occasional winter there is a heavy snowfall and the snow on the ground accumulates to a considerable depth, but as a rule, the snow covering over the State during the winter is not great.

The average annual temperature is rather low, the Weather Bureau records indicating an average of about 46° for the area, with an average annual range of about 136°. The winters are long and severe. The cold, however, is rendered less noticeable by the dryness of the air. The winds are a very important climatic factor of this region, strong winds being very frequent in every season of the year. From December until March the prevailing direction of the wind is from the northwest or north, resulting in blizzards and very low temperatures.

Evaporation data are not available.

HISTORICAL DEVELOPMENT

Fur trading with the Indians was the first industry of this territory and was quite profitable until about 1878, when the settling up of the country resulted in the disappearance of the game. Although trading posts were established in this region by the early French fur companies, the Indians were hostile to settlers and there was little agricultural development west of Big Sioux River until about 1862, when treaties with Indians made this land available. The early settlers made their homes along the Sioux River. This was done in order to take advantage of the narrow strip of timber along the stream, and because of the protection from prairie fires which the river afforded. Prairie fires were of frequent occurrence and were a source of great danger and loss to the settlers so long as the prairie remained unbroken. About 1872 the line of the Chicago, Milwaukee & St. Paul Railway was built into southwestern South Dakota, and by 1880 the territory had been largely homesteaded. This drainage area is primarily an agricultural section, producing large acreages of corn, wheat, and oats. Native hay is produced in nearly all parts of the upland on poorly drained lands.

There are neither extensive forests nor large bodies of water in this area. In the Big Sioux Valley there are numerous small groves of timber, principally cottonwood, box elder, and ash, ranging from 1 to 10 acres or more, in areas that have been planted and cared for by farmers. There is very little natural timber found in the area and such as is found is in the form of narrow fringes along the streams. The country is naturally a prairie region.

The timbered area has been increased to a small extent by the planting of groves. There is a limited acreage of woodland being cleared for crops, but on the whole there is little change taking place.

CONDITION OF LANDS OTHER THAN FOREST

(*a*) The 1925 agricultural census shows that 90 per cent of this area is included within farms and that approximately 69.3 per cent of the area is classified as crop land, producing corn, wheat, oats, flax, and potatoes, and hay as the principal crops. Cultivation of the soil is such as to store up as much of the rainfall as possible and the run-off is reduced proportionately, resulting in a low degree of erosion.

(*b*) The unimproved lands include chiefly the rougher lands and grassland areas used principally for pasture. This class will include about one-fourth of the whole unit. On these unimproved lands the cover of grasses and other vegetation gives effective protection against erosion which on a bare surface would be excessive. The grassland areas are pastured and there is no longer a serious fire problem. The tendency is more often toward overgrazing which results in some erosion and gullying. The area is quite well drained naturally and artificial drainage is unnecessary.

CONDITION OF FOREST

The forest area within this unit is very small. The timber consists only of the one type—upland hardwoods, and its proportion of the area is, according to 1925 agricultural census figures, approximately 0.86 per cent.

A. Cutting for lumber has never been of consequence here, although early settlers used limited amounts of the native timber for buildings.

B. Forest fires have not been a problem and little damage to timber has resulted from that cause.

C. Grazing of woodland areas is quite generally the practice in this unit and has been more or less detrimental to the timber itself, especially in damaging young reproduction by trampling and browsing. Trails made by the stock are the first place in which erosion takes place. This is especially true on the steeper slopes.

D. Drainage by artificial means has not been necessary and very little of it has been done. Mention is made in one of the soil-survey reports of the existence of several feet of water in certain depressions when settlers first came to the region. Such places are now dry. This is explained by the gradual lowering by erosion of the level of the soil surface at the outlets and surplus waters are readily drained off at the present time.

E. In general, the forest conditions are such in this unit that their influence and value are largely of very local application. Planted timber about farm buildings and a limited area of natural timber along the streams comprises the woodland acreage. Cottonwoods, box elders, and ash are the predominating species of hardwoods. Red cedar is the only native conifer. All these are growing in open, scattered stands and are of inferior quality.

Protective value of the watershed

Rated as follows:

(*a*) Soil: Loam soil, 100 per cent of area, rated at		75
(*b*) Topography—		
80 per cent of area practically level, rated at 100 per cent effectiveness	80	
20 per cent of area steeper slopes, rated at 50 per cent effectiveness	10	
		90
(*c*) Precipitation—		
50 per cent of rainfall in heavy downpours, rated at 50 per cent	25	
50 per cent of rainfall in form of snow and gently falling rains, rated at 100 per cent	50	
		75

(*d* and *e*)	34.65 per cent of the area in corn, potatoes, etc., rated at 50 per cent	17.325	
	64.49 per cent of the area in grass and pasture land, rated at 75 per cent	48.37	
	0.86 per cent in forest, rated at 100 per cent	.86	
			66.55
	Total		306.55
	Average rating		76.6

The average rating as shown above is comparatively high for this section, resulting from the rather flat relief with its loam soil, which is not appreciably eroding in any place. A heavy percentage of the total area is crop land, producing varied crops, with corn among the principal crops grown. The area in pasture and hay land makes up the greater portion of the unimproved lands, with forested areas of less than 1 per cent. The area does not have a high annual precipitation and conditions are not serious from the standpoint of excessive run-off and erosion anywhere within the unit.

CRITICAL FOREST AREAS

There are no data available indicating within this area the existence of any critical areas as affected by erosion or flood conditions. The forest area is very small but there are unquestionably many small local areas which individually might be considered as critical. Information as to this would not be obtainable except through careful survey of the areas in question. All such possible areas are on private lands and in most cases corrective action, if taken, will depend upon the value of the area to be protected and the cost of the work necessary. Forest planting for protection of watersheds or eroding lands has in reality been given very little, if any, attention in this region. As a whole, however, there are no areas which, from the standpoint of erosion and flood control, are recommended as critical.

RECOMMENDATIONS FOR THE WATERSHED

A. The area to be retained in forest should, under no conditions, be permitted to become less than at the present time. The present forest area, as shown by the 1925 agricultural census figures, is but 0.86 per cent. This small percentage expressed in actual area amounts to but 44,031 acres. This percentage in forest is but little changed from the original native woodland area found by the early settlers. Some lands have been cleared and placed under cultivation, but planting of windbreaks and groves on farms has helped to maintain the original area.

B. At present fire protection is not a serious problem within this region. Very little fire occurs in timber and the individual owners in each case now assume the responsibility for protecting their own timber.

Protective measures against other agencies, such as insects, disease, etc., are largely unnecessary. Assistance can usually be secured from the State agricultural colleges.

Proper methods of cutting and management to insure prompt restocking are important to prevent decreasing of the forested area. The State should have some control over such cuttings.

Forest planting is believed to be the greatest field for improving conditions within this unit. Windbreak, shelter-belt, and wood-lot planting is unquestionably needed and should be encouraged through such agencies as may be made available. Clarke-McNary law cooperation and aid in tree planting should be extended and liberalized as fully as possible. This should be made to permit planting for parks and watershed areas of towns or municipalities, as well as on farms, and the benefits extended to every possible tree-planting agency. Tree planting on all the rougher lands within farms should be encouraged, and a farm survey should be made by extension foresters to determine the location and extent of such areas on which tree planting is needed.

Grazing management of forests is important since nearly all present woodland is pastured and, as a result, natural reproduction is restricted. Under present economic conditions, and with the timberland all privately owned, the most feasible method of improving this seems to be through the educational activities of the extension service of the States.

WHITE RIVER

(Area 62)

LOCATION AND AREA

The White River drainage includes 8,479 square miles in the western portion of southern South Dakota and 1,730 square miles in the extreme northwestern part of Nebraska; 10,209 square miles in all. The river itself flows northeast for the upper third of its length through Nebraska and South Dakota, then east through South Dakota, emptying into the Missouri about 75 miles below Pierre.

On the west it joins the Cheyenne River drainage which covers all of southwestern and most of western South Dakota. To the north the Cheyenne continues to parallel the White but is separated for about one-half the length of the White by a small stream emptying directly into the Missouri at Pierre, known as the Bad River. Along the south is the Niobrara drainage and to the east the main Missouri.

TOPOGRAPHY

The White River drainage contains no typical hills or mountain areas, although it presents in spots an extreme of ruggedness for plains country. This and other rivers in western South Dakota are bordered by very broken, sometimes almost mountainous country, the larger areas being found along the Missouri and the lower portions of the other streams.

> Throughout a large proportion of the plains the next prominent feature of the landscape is the occurrence of isolated hills or buttes which rise from 50 to 500 feet above the surrounding country. * * *

According to the authority just quoted 56 per cent of South Dakota west of the Missouri River is level and rolling, permitting of cultivation by use of farm machinery; 23 per cent is heavily rolling to hilly, making the use of machinery difficult (in some areas impracticable); 21 per cent is rough, adapted to grazing only.

There is a somewhat greater proportion than this of hilly and rough land in the area of the White River drainage. So much for the general character of the topography of this drainage. A more detailed discussion may best consider the various types of topography as they are encountered proceeding from the source of the river to the mouth.

Pine Ridge, in northwestern Nebraska, in which the White River has its source, is high rolling country.

At the source of the river the altitude is about 4,250 feet above sea level. Here there are occasional hills and ridges of dunelike appearance, heaped up by the wind, also patches of white calcareous rock and stony ledges exposed by the wind.

Where the river crosses 103° 30′ this topography gives way to moderately rolling ridges and slopes. Areas of dunes and bad lands are small. This continues along both sides of the river bordered along the upper margin of the basin on the south side by rough broken land and bluffs.

The topography then changes a short distance below White Clay Creek to the bad lands, especially north of the river.

Bad Lands, so called, occur in areas of varying size throughout western South Dakota. The term is used indiscriminately to indicate (1) a type of topography or (2) a section in which this type of topography predominates. Used in the latter sense, however, it does not mean that the typical eroded, barren waste usually pictured as the Bad Lands is found to be continuous by any means. This comes nearer being the case in an area along the north side of White River between Scenic and Kadoka (on the Chicago, Milwaukee & St. Paul Railroad) than any other place. These are known as the big Bad Lands as distinguished from other similar small regions or from the entire upper half of this river drainage which is sometimes called the White River Bad Lands, including everything from Pine Ridge to approximately the one hundred and second meridian, a distance of 120 miles.

Bad-land formations, especially the big Bad Lands, represent an extreme case of erosion, and in many portions are so badly gullied that travel, even on foot, is practically impossible. Because of the importance of erosion in this type of topography more attention is given to it than to any other. The most rugged portions are Sheep Mountain, the Great North Wall, the Castle Butte country, and the South Wall, overlooked by Eagle Nest Butte, between Scenic and Kadoka.

This area covers several townships and is broken only by a few bad lands basins. Considerable areas occur at intervals along White River, usually a distance of several miles from the stream.

The Bad Lands have been produced by the rapid erosion of soft rocks and are more common in the Laramie formation in the northwestern part of South Dakota and in the White River group in the southwestern part. Along the slopes of swiftly flowing streams the silty soils and the underlying soft, silty shales have melted away and great gullies and gorges with steep slopes have been cut. Over large areas these gullies run together so as to cover the entire surface, breaking up all the original plateau or leaving only small

tables standing above the dissected waste. On large areas of the Bad Lands the topography may take various forms, depending upon the rapidity of erosion and the time which has elapsed, during which the sharp forms originally left could be smoothed by further weathering. There may be ranges of thin, jagged hills with sharp combs and ridges or large tracts cut down to the lower clays and covered by round bare hills. Pyramidlike buttes are a feature of the region and castellated forms and carvings of fantastic shapes all go to make up a scene of the utmost desolation. In nearly all the smaller tracts the bare and useless aspects of the Bad Lands is broken by filled-in valleys, slopes upon which vegetation maintains a precarious stand, and flat-topped, grassy buttes, which have escaped in the down wearing of the country. Such small and irregular tracts, while not available for farming, constitute some of the best grazing land in the Northwest.

The southern edge of the river valley here, on the other hand, is a broad, level, very gently rolling plain. This is around the head of the Little White. The slope toward White River is a plain broken by parallel northward-flowing streams, several miles apart which have a rapid fall toward White River. There are patches of bad lands, usually several miles from the river. This area becomes rougher and steeper as it slopes down to the river.

The lower portion of the valley, though broken along the river, is in general a smooth, rolling plain along the outer edge.

The altitude at Chamberlain, a few miles up the Missouri from the mouth of the White River, is 1,353. No data are available on the length of the stream and very little on the rate of fall but the basin is approximately 250 miles long by about 60 miles wide.

The fall of the river at the old station (1904–1906) near Interior is 3 feet per mile. The velocity of the stream is as follows:

Date	Maximum feet per second	Minimum feet per second	Mean feet per second
1904	1.41	0.81	1.14
1905	2.24	1.47	1.40
1906	2.15	1.84	2.00

The stream bed at the station (1904–1906) was described as sand and gravel and shifting. At the station located in 1911 a few miles away it was described as sand, some quicksand. At the old station there was but one channel at all stages except the very lowest when there might be several.

The main floods seem to occur in March, May, June, and July. The flow is erratic. In 1905 the stages varied between 1 foot and 16 feet. On June 17 the height was 4.2 feet, discharge 1,060 second-feet; on June 18 the height was 16 feet and the discharge 16,500 feet. The discharge dropped again on the 19th to 2,250. There were no severe floods in 1904 or 1906. In 1911 the maximum stage was 10.5 feet and in 1912 the maximum was 8 feet during the open season.

Discharge of White River, Interior, S. Dak.

Year	Low, second-feet	Date	High, second-feet	Date
1913	5	Mar. 1–2	4,720	June 14.
1914	0	Sept. 13–15	950	Mar. 9.
1915		Sept. 19–29		
1916	0	Oct. 1–4	8,550	Apr. 26.
1917	24	Sept. 10–16	5,320	May 21.
1918	8	Sept. 8–13	3,260	Mar. 30.
	8	Oct. 12–13	2,500	July 17.

Extremes of flow, White River, S. Dak.

Dates:	Discharge second-feet
June 17, 1905	1,060
June 18, 1905	16,500
June 13, 1913	365
June 14, 1913	4,720
June 15, 1913	940
June 16, 1913	320
May 20, 1916	140
May 21, 1916	5,320
July 16, 1916	439
July 17, 1916	1,820
July 18, 1916	700

The drainage area above this station is 5,005 square miles (1904–1906;[1] 4,090 square miles 1911[2]) or less than half the whole valley.

No information is available on storage reservoirs, either natural or artificial, although according to Professor Aldus, Kansas State College, there is little of the stream suitable for either type of development.

GEOLOGY AND SOILS

A. *Geological formations.—*

The White River deposits consist principally of a pale, flesh-colored to almost white silt loam, which often contains beds of fuller's earth. In its extension north of the White River it changes to silty clay or clay. These formations give rise to silt loam, silty clay loam and silty clay soils. * * * A considerable part of the area covered by the White River group is very badly eroded, and is classed as "Bad Lands" or "Bad Land Basins." (1)

The materials making up the Band Lands are chiefly unconsolidated clays, sands, and gravels, the clays greatly predominating. Thin sandstones and conglomerates occur locally and nodular concretions are often abundant. Dikes of sand and clay are common in places. A thin bed of volcanic ash occurs among the higher deposits, but this is of subordinate importance and has little immediate connection with the fundamental cause of the Bad Lands.

The Bad Land basins represent areas where erosion has been checked either by wearing down to more resistant material to practical base level. The material, which is being rapidly washed away from the Band Lands, is arrested and spread out more or less over these basins.

According to this a large part of the silt carried by the stream here is deposited before it reaches the Missouri. This is the only information available on this point.

B. *Soils.*—The soils of the White River drainage are practically all various combinations of clays, loams, and silt. In the Pine Ridge

[1] Sec. 10, T. 4 S., R. 18 E.
[2] Sec. 7, T. 4 S., R. 18 E.

country the extreme source of the river is in silt loam. From this point loam, especially silt loam, predominates on the south side of the river nearly to where it crosses the one hundred and first meridian, with a high-grade fine, sandy loam along the upper border. Beyond this point the valley on both sides is predominantly clay.

On the west and north side of the river there is clay principally until the Bad Lands are reached where the soil is largely silt loam with clay in some of the lower valleys, down to the clay loam and clay which begins at about the one hundred and first meridian.

The loam at the head of the drainage is typically 12 to 20 inches deep. The soil is not friable at first but improves under tillage. There is usually enough sand to give it a gritty feeling. The subsoil varies chiefly in the smaller content of organic matter. Erosion has gone on very rapidly leaving only a thin layer of soil on the unweathered brule clay.

The silt loam farther down the valley is about 10 inches deep and very silty. The sand in the soil is composed of the very finest grades. The subsoil, to a depth of 2 feet, is a silty loam, containing in most places, more clay than soil.

The Rosebud silt loam is loose and friable and is easily brought into good condition for tillage. The principal difficulty in handling this type is due to its tendency to wash. The silty material melts away rapidly under running water and on slopes and hillsides the erosion is excessive, so that eroded spots and incipient Bad Lands topography are a feature of the hilly areas. * * * The Bad Lands, which have been mapped as a separate type, represent badly eroded country once covered by the Rosebud silt loam. On the broad level or gently rolling flats and valleys it will not be difficult, with a little care, to prevent gullying, but where there is any considerable slope washes must never be allowed to start.

The following table gives the average results of mechanical analysis of samples of soil and subsoil of the Rosebud silt loam.

Mechanical analyses of Rosebud silt loam

Analyses Nos.	Description	Fine gravel	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
22440, 22442	Soil	0.4	0.5	1.0	4.9	28.2	55.3	14.6
2441, 22443	Subsoil	.2	.5	1.0	1.6	16.5	62.8	17.4

The sandy loam which occurs in a belt between the Sand Hills of northern Nebraska and the silt loam farther north along White River is 12 to 18 inches deep and varies from loamy fine sand to fine sandy loam, sometimes containing a large percentage of silt. The subsoil has an equal or greater amount of silt.

The clay of the lower portion of this region belongs almost altogether to the Pierre series.

The most distinguishing characteristic of the Pierre clays is their sticky nature, which has given them the local name of "gumbo." The soil varies considerably in texture as well as in color, but this sticky nature is a constant feature. In texture the material ranges from a silty clay loam through a silty clay to a heavy clay. * * *

The subsoil, which is encountered frequently at a depth of 6 to 10 inches, is a silty clay. * * * Soft shale is usually encountered at 3 to 6 feet below the surface and on some of the badly eroded areas comes to the surface.

A very characteristic feature throughout the area of Pierre clays is the cracking of the soil upon drying. * * * In some instances these extend to a depth of several feet. This tendency to crack * * * is a valuable property. * * * It also permits the rains to enter much more easily.

The last-mentioned characteristic indicates a fairly effective obstacle to erosion in addition to any resistance inherent in the texture of such soils. It also increases absorption.

CLIMATE

Precipitation for the White River drainage is summarized in the following tabulation:

Precipitation in White River drainage basin

Station	January	February	March	April	May	June	Years' record
Fort Robinson, Nebr	0.59	0.60	1.12	1.76	2.66	2.54	1883–1920
Chadron, Nebr	.46	.78	1.02	3.14	3.14	2.67	1894, 1914–1920
Pine Ridge, S. Dak	.26	.41	.86	2.02	2.91	2.83	1901–1908, 1913–1920
Interior, S. Dak	.31	.38	.72	1.85	2.92	2.22	1897–1903, 1916–1920
Kadoka, S. Dak	.36	.81	.68	2.43	3.28	2.43	1909–1920
Rosebud, S. Dak.[1]	.85	.73	1.31	2.22	2.65	2.63	1892–1920
Murdo, S. Dak	.66	.70	.98	2.54	2.90	2.75	1907–1920
Wood, S. Dak	.67	1.04	1.05	3.21	3.69	2.84	1913–1920
Average	.52	.68	.97	2.40	3.02	2.61	

Station	July	August	September	October	November	December	Annual	Years' record
Fort Robinson, Nebr	2.04	1.62	1.16	1.31	0.36	0.73	16.49	1883–1920
Chadron, Nebr	2.18	1.71	1.49	1.12	.70	.59	19.00	1894, 1914–1920
Pine Ridge, S. Dak	2.47	1.64	1.37	1.29	.28	.58	16.92	1901–1908, 1913–1920
Interior, S. Dak	2.04	1.20	1.01	1.00	.55	.34	14.54	1897–1903, 1916–1920
Kadoka, S. Dak	1.90	2.31	1.37	.96	.32	.50	17.35	1909–1920
Rosebud, S. Dak.[1]	2.61	2.04	1.16	.95	.62	1.00	18.77	1892–1920
Murdo, S. Dak	2.60	1.86	1.18	1.34	.42	.63	18.56	1907–1920
Wood, S. Dak	2.86	2.45	1.52	1.18	.95	.74	22.20	1913–1920
Average	2.34	1.85	1.28	1.14	.53	.64	17.98	

[1] In many cases data based on estimates from surrounding stations. Annual extremes for May are as follows:

	High	Low
Rosebud:		
1894		0.27
1908	6.50	
Interior:		
1901		.18
1918	5.47	

Averages vary accordingly.

Bulletin W: Summaries of Climatological Data, by Sections, second edition, Volume II 1926. Weather Bureau.

The above tabulation indicates much greater regularity and consistency than actually exists, because of the number of years which have been averaged. The variation from year to year at the same station is considerable, as may be noted in the following record for the month of May (the month of greatest precipitation throughout the whole drainage) at Wood, Mellette County:

Precipitation for the month of May at Wood, S. Dak.

1913	2.78	1918	2.90
1914	2.36	1919	2.77
1915	4.52	1920	5.63
1916	3.05		
1917	5.54	Mean	3.69

This shows an annual variation from nearly 1 inch below to 2 inches above the mean. The extremes at Interior are 1.1 and 5.47 for the same month (12-year record), and at Kadoka 1.14 and 5.78 (12-year record). Furthermore, the occurrence of precipitation within a given month is somewhat erratic although records to show this are lacking here. It is significant, however, that the annual peak occurs consistently in May and that the averages for the eight stations do not show one instance where the precipitation for either April or June equals that for May. Although in some cases the precipitation for June in a given single year may exceed that for May, that for April rarely does.

This is significant since the temperature records indicate heavy snow melting in March, far enough in advance to separate these two causes for floods. (See following table.)

Mean temperature, White River, S. Dak.

Station	January	February	March	April	May	June	Year's record
Fort Robinson, Nebr	23.0	23.2	33.5	45.8	54.5	65.0	36
Chadron, Nebr	21.6	27.1	35.0	43.7	54.5	65.8	6
Pine Ridge, S. Dak	22.0	23.3	35.2	45.4	54.5	64.3	12
Kadoka, S. Dak	18.0	19.6	34.0	46.7	56.1	68.1	10
Murdo, S. Dak	18.5	21.0	33.8	46.5	56.0	67.6	13
Rosebud, S. Dak	22.8	22.1	32.5	47.0	56.8	66.5	20
Average	21.0	22.7	34.0	36.0	55.4	66.2	16

Station	July	August	September	October	November	December	Average	Year's record
Fort Robinson, Nebr	71.1	69.8	60.6	47.7	35.6	26.5	46.4	36
Chadron, Nebr	73.9	70.9	62.5	48.5	33.4	27.5	47.0	6
Pine Ridge, S. Dak	72.9	70.2	60.8	47.4	37.4	24.1	46.4	12
Kadoka, S. Dak	74.6	71.9	62.4	50.7	37.2	22.3	46.8	10
Murdo, S. Dak	74.7	72.1	64.0	49.7	36.7	22.6	46.9	13
Rosebud, S. Dak	73.4	71.0	61.1	49.0	36.4	24.0	46.9	20
Average	73.4	71.0	61.9	49.0	36.1	24.5	46.7	16

Bulletin W: Weather Bureau.

Snowfall, White River drainage, South Dakota

Station	January	February	March	April	May	June	Year's record
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	
Fort Robinson, Nebr	6.7	5.8	10.2	6.5	1.0	0	23
Chadron, Nebr	7.0	10.1	10.9	17.6	1.6	0	7
Pine Ridge, S. Dak	3.7	5.1	7.7	6.9	.7	0	13
Kadoka, S. Dak	3.7	4.5	4.2	2.8	.3	0	10
Murdo, S. Dak	6.6	7.6	8.6	6.0	.6	0	11
Rosebud, S. Dak	7.6	7.5	9.4	3.8	.2	0	20
	35.3	40.6	51.0	43.6	4.4	0	
Average	6.0	6.8	8.5	7.2	.7	0	

Station	July	August	September	October	November	December	Total	Year's record
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	
Fort Robinson, Nebr	0	0	T.	3.1	3.0	6.5	42.8	23
Chadron, Nebr	0	0	T.	2.6	6.9	7.3	64.0	7
Pine Ridge, S. Dak	0	0	T.	2.2	3.8	6.4	36.5	13
Kadoka, S. Dak	0	0	.1	1.5	2.3	2.8	22.2	10
Murdo, S. Dak	0	0	.5	.4	4.4	6.2	40.9	11
Rosebud, S. Dak	0	0	.3	1.6	4.5	10.3	45.2	20
	0	0	.9	11.4	24.9	39.5	251.6	
Average	0	0	.15	2.0	3.15	6.6	32.0	

Bulletin W: Weather Bureau.

The sufficiency of this separation between snow melting and rainfall is further emphasized by (1) the prompt run-off in this type of country (see stream-flow records) and (2) the fact that most of the snowfall occurs between January and March indicating more rapid melting than if it fell between November and January and had a chance to settle. (See snowfall table.) Although the snowfall for April is considerable, because of the season and temperature this amounts to nothing more than rain.

Referring again to the temperature table, one would be justified in assuming that all of the snowfall of October and November and a large part of that in December would have opportunity to soak into the ground before it froze. The same would be true in April.

The prevailing winds at Rosebud, the only station on this drainage in South Dakota for which records are available, are from the northwest, December–April; south, May–July; southwest, August–September; northwest, October; and southwest, November. At Chadron and Fort Robinson in Nebraska, it is from the southwest throughout the year except September at Chadron (west) and November at Fort Robinson (west). This would favor early melting in the spring and probably rapid melting throughout the year at the headwaters of the river where the snow is deep and later melting down the valley.

There is no information available for the wind velocity on this drainage. In general, for western South Dakota—

Winds often blow steadily for several days at a time, with only short periods of calm between. The average annual velocity at Pierre is 9.3 and at Rapid City 8.1 miles per hour. March, April, and May are the windiest months, the average velocity at Pierre during April being 12.2 and at Rapid City 9.3 miles per hour.

* * * most of the precipitation is in the form of snow, much of which remains until spring, when it melts, and if the soil is in proper condition, runs into the ground.

Killing frosts occur mainly between September 10 and May 15.

The seasoned distributing of precipitation favors vegetative growth.

Evaporation is high due to low relative humidity, high summer temperature, and persistent wind. It amounts in this section to 40 to 50 inches per year. This modifies the vegetation which might otherwise be expected to accompany the precipitation which occurs here.

HISTORICAL DEVELOPMENT

The first settlement recorded within any of the counties of the White River drainage in South Dakota occurred in 1890 in Lyman. It is safe to assume this was on the Missouri River. The next settlement among these counties was 1904. Settlers became fairly numerous in sections of these counties about 1905 to 1910, although it is not well distributed even to-day. Population in the Nebraska portion increased somewhat earlier but probably did not amount to much before 1880.

The 1910 population in the South Dakota portion of the drainage did not exceed 2 per square mile on about four-fifths of the area and was rated at 2–6 per square mile over the rest. There has been no considerable growth since then. Production of all sorts through industry and agriculture are at a minimum.

There were about 20,000 Indians in the State in 1910. The majority of these to-day are located on White River. This accounts, to a large measure, for lack of development here.

According to agricultural census figures for 1925, 11 per cent of the area of 10 counties lying partly within this drainage (omitting Lyman and Tripp which lie also along the Missouri and are not typical) were at that time crop land and subject to cultivation. Of this percentage, 44 per cent is in hay having 56 per cent cultivated or 6 per cent of the total. In the same counties 1.9 per cent of the area is covered by farm woodlands. Since farm lands make up on the average only about 40 per cent of the total area of these counties (with the exception of the small area at the upper end of the drainage in Nebraska where it is higher) this leaves a large portion of the region for which there is no reliable information. According to the vegetative type map by Shantz and Zon, this is all short-grass type except a strip of western yellow pine on Pine Ridge around the head of the valley and a fringe of "oak-hickory," probably mostly cottonwoods, along the stream bottoms. However, there is scattered western yellow pine over much of the higher portion of the drainage, according to Professor Aldous, of Kansas State College. The eroded Bad Lands areas together with the cultivated area probably equals 15 per cent of the total.

Condition of lands other than forest

Type	Per cent of area	Area
Cover types, White River drainage:		*Square miles*
Open grass	67	6,840
Open grass and scattered timber	15	1,532
Bad Lands and eroded	5	511
Cultivated	6	612
Hay	5	510
Bottom timber and pine timber	2	{ 50 154
Total	100	10,209

These figures were derived from the following table compiled from the United States Census of Agriculture, 1925, Nebraska and South Dakota. They are arranged for 10 counties lying partly within the White River drainage, omitting the 2 which are bordered also by the Missouri River.

Total area .... acres	8,836,480
Farm area:	
Per cent	58.4
Acres	5,159,839
Cropped area:	
Per cent	11
Acres	962,159
Hay:	
Per cent	4.8
Acres	425,689
Cultivated:	
Per cent	6.2
Acres	536,470
Woodland:	
Per cent	1.9
Acres	165,408

Hay area subtracted from cropped area. The hay, cultivated and woodland percentages were then applied to the total area of the drainage. The remaining 82 per cent was divided according to the proportion of the drainage in Nebraska and South Dakota into grass with scattered trees (Pine Ridge) and grass. Bad Lands estimated from soil map. Timber types divided by rough estimate. (Census report.)

Most of the land in this drainage is covered with typical short-grass vegetation. About 11 per cent is barren and erodible (cultivated and Bad Lands). The grazing land is not heavily enough stocked to involve danger from erosion. The crop-land area, equaling 11 per cent, is probably not intensively cultivated (5 per cent hay, 6 per cent cultivated). By the same token it is probably not very carefully handled, which may be an important factor in a region of fairly steep slopes.

CONDITION OF FOREST

(A) All the rivers and larger creeks were originally bordered by a fringe of trees, consisting principally of cottonwoods, ash, elm, and box elder. Sometimes these belts are not more than 50 to 100 feet in width; sometimes they widen out to a mile or more. * * *

According to this authority, this timber has been cut extensively for fuel, fence posts, and building material.

Lumbering has not been so important a factor in the pine type because of its open character and the slight extent to which it has been cut.

B. *Effect of fire.*—Negligible, except in retarding reproduction on Pine Ridge.

C. *Effect of grazing.*—The small number of livestock grazed in the area does not involve the danger of erosion.

D. *Effect of drainage.*—There are practically no swamps of importance in this region and no natural storage reservoirs according to Professor Aldous. Run-off is very rapid and quickly responsive to precipitation and other sources of surface water.

E. Forest conditions (pine type) exist around the head of the drainage (Pine Ridge) and along the stream bottoms (lowland hardwoods). Woodland areas are scattered over the high ground in the upper half of the drainage. The effect of this cover on floods, except in the bottom type where it probably favors moisture retention, is pretty well limited to the prevention of erosion.

PROTECTIVE VALUE OF THE WATERSHED

(*a*) *Soil.*—Clay rates low, silt loam should be low because of demonstrated susceptibility to erosion. Bad Lands speak for themselves.

	Area	Rating
	Square miles	
Silt loam	6,000	50
Clay	3,500	50
Bad Lands	500	50
Weighted average		50

(*b*) *Topography.*—Rolling country, not extensively steep, retention practically negligible.

(*c*) *Precipitation.*—1. Snow melting and precipitation peak both during Missouri flood period, March to June.

2. Melting and precipitation well distributed over period.

3. Precipitation erratic and run-off responsive. Rated as 50.

(*d*) *Cover.*—1. Cover of little value except to prevent erosion.

2. Cover lacking on 11 per cent of area and where most easily erodible soils occur.

3. Absorption and retentive qualities low.

4. Very little level ground.

5. Bottom-land forests heavily cut over.

Type	Area	Rating
	Square miles	
Hay	510	100
Timber	204	100
Grass	8,372	75
Bad Lands, eroded	511	50
Cultivated	612	50
Average for the watershed		62

CRITICAL FOREST AREAS

The bottom forest types should be preserved and extended to cover all of this potential type not necessary for farming. A serious feature of floods here is cut-bank erosion and consequent swelling of flow volume.

Fort Robinson timber reserve, 16 sections, should be handled so as to preserve the forest cover. If there is any question about this being practical under the present administration, it should be transferred to the Department of Agriculture and handled as national-forest land. Such a transfer might form the nucleus of an acquisition project. At any rate, planting on privately owned land in this region should be encouraged under the Clarke-McNary law.

The pine ridge timber, at any rate, should be preserved both for its value in holding moisture and preventing erosion.

The matter of extending the range of forest growth by planting is problematical. Experimental plantings in the region of eroded bad lands might be worth while to find out to what extent the deeper rooting systems of trees would check erosion which is not stopped effectively by other vegetative cover alone. It is not likely that forests so planted on the uplands would have much other value except for fence posts and fuel.

RECOMMENDATIONS

A study of the White River and its watershed does not show any very direct relation between conditions here and the Mississippi floods, or even the Missouri, except, possibly, erosion in the Bad Lands. However, it is one of many small contributing streams, the effect of which may, accordingly, be multiplied many times in the case of uniform climatic conditions extending over a wide territory. With this understanding, the following recommendations are made, primarily as a margin of safety in connection with floods in the larger streams, secondarily for their value in local watershed protection.

(A) (1) All the area in western yellow-pine forest at the headwaters of the stream on what is known as Pine Ridge should be maintained, also the hardwood growth along streams throughout the drainage. This would make a total of about 2 per cent of the watershed. Attention should be given to rehabilitating both types where they have been cut heavily. All the land with the exception of the Fort Robinson timber reserve is in private ownership. Parts of the Rosebud and Pine Ridge Indian Reservations are still under Government administration.

(2) Cutting should be done in all cases so as to favor the establishment of true forest conditions, subject, of course, to the need of the land for grazing.

Because of the land ownership here these recommendations will have to be put into effect through the efforts of an extension forester. This is possible in Nebraska.

(B) (1) Protective needs are negligible at present except on Pine Ridge where railroad fires occur practically every year. These are grass fires and rarely do damage to mature timber. However, their occurrence prevents reproduction from getting a start and will, therefore, eventually pinch out the stand.

Railroads should be checked up on spark arresters and interested in patrol and other means to avoid such fires. This should also be done by the extension forester.

(2) Planting on private lands on Pine Ridge under the provision of the Clarke-McNary law should be encouraged.

Experimental plantings should be established in the Bad Lands to test the practicability of reforestation on these lands which are not eroding badly.

(3) Provisions for adequate protection of the Fort Robinson timber reserve should be assured. The advisability of handling as national forest land should be considered further, primarily as a watershed protection measure. Under forest administration it would serve as a nucleus in the wider but somewhat lower quality timberland surrounding, to be used as (*a*):

(*a*) Demonstration area from which the ranger in charge could push, advise, and assist planting on private lands; or

(*b*) To form the center of an acquisition unit in which a larger national forest could eventually be built up through purchase.

(4) For the present it should be a duty of the Nebraska extension forester to inspect this region for insect danger and fire and strive to get cooperation of owners in protecting and properly using stands both for timber and grazing.

(5) South Dakota should appoint an extension forester to handle similar activities in that State and should take advantage of the provision of the Clarke-McNary law for the distribution of forest tree planting stock.

(6) Grazing on unsold Indian lands in the Pine Ridge and Rosebud Reservations should be regulated with watershed protection in view as a major objective. At any rate steps should be taken to prevent overgrazing on these lands as the tendency increases to stock the land more heavily in response to the improvement of livestock economic conditions.

GASCONADE RIVER

(Area 63)

LOCATION AND AREA

The Gasconade is the largest tributary from the south near the mouth of the Missouri River. It rises in Webster County, flows through Wright, Laclede, Pulaski, Phelps, Maries, and Osage Counties and empties into the Missouri River about 100 miles above its mouth into Gasconade County. The drainage basin is about 130 miles long and 50 miles wide near the southern end from which it gradually decreases to 15 miles near its middle, maintaining this width to the mouth. The total area of the basin is 3,540 square miles.

TOPOGRAPHY

The basin occupies a nearly central position on the northern slope of the topographic province known as the Ozark Dome. Its mouth has an elevation of about 600 feet, the upper parts of the basin at the south rising to a general altitude of 1,300 feet with isolated

points 100 feet higher. It represents the remnant of two plains of different geological periods. The land lying at the higher altitude on the divides between the streams is the remnant of a plain which has been dissected the least by stream action; those areas near the streams as a rule have been dissected so deeply that the breaks on each side of the streams are rough and hilly and in places intricately dissected, especially along the larger streams toward the north. Some of these interstream areas are nearly level and at the time of settlement were prairies or open park like woods. Some were dotted with occasional clumps of trees except in Maries County, where limited swamp areas occur. There were no extensive swamp lands. The small areas of swamp lands and the alluvials have been largely drained, although much additional work in the way of tilling is still necessary. Approximately 60 per cent of the area can be classed as hilly, rough land, and 40 per cent as rolling and level.

GEOLOGY AND SOILS

This basin lies largely within the region occupied by Cambrian rocks represented particularly by carbonates such as limestone and dolomite. There are limited areas of sandstone and shale. A characteristic feature of the soils is a large amount of chert and gravel which is incorporated, or which lies as a drift upon the surface.

The soils are prevailingly loams and clays, largely gravelly, stony, or with chert intermixed or scattered over the surface. There are limited areas of silts and sands, the largest sand areas being in the southeastern part of the basin. On account of the gravelly nature of the soil drainage is generally good, tending to reduce erosion. Such erosion as takes place is prevailingly sheet except along the streams which are subject to cutting and washing on account of the frequent floods. Erosion is not so active or of such a deleterious character as on the silt soils to the north of the Missouri River.

CLIMATE

The precipitation is practically uniform over the entire basin, averaging about 44 inches; about two-thirds of which falls during the six summer months. The snowfall is light, averaging about 16 inches before melting. This region has been extensively advertised as a fruit-growing section. The climate is characterized by severe late frosts which have prevented its development. There was a shrinkage within one decade of one-half of the number of apple trees and nearly 30 per cent of the peach trees, due to repeated injury to buds by such freezing. It is possible that this climatic factor may have been important in restricting the forest growth over this basin. The basin lies within the region of heavy midsummer thunderstorms, an average of about 50 occurring each season.

HISTORICAL DEVELOPMENT

Permanent settlements on the basin for agriculture began between 1825 and 1830. However, on account of the roughness of the country, and the medium character of the soils, settlement was slow. Because

of the rough condition of a great part of the land surface and the poor character of many of the hill farms, lumbering and especially the making of ties has been an important industry. Pine timber of excellent quality grew on the sand sites along Big Piney Creek at the southeastern end of the basin. For many years this timber was cut and floated down the river. Later it supplied local sawmills and has very largely been cut out. Many areas have been so closely cut as nearly to exterminate the pines. At the time of settlement there were a number of prairies occupying the most level lands on the divides between the streams. These prairies contained bluestem and other rank grasses. Since the settlement of the country there has been a great extension of forest on these prairies. In fact it is probable that there is a larger proportion of the area of the basin in timber today than at the time of its settlement. Much of the woodland consists of open stands, black oak, white oak, blackjack, and post oak being the predominant species. A large part of the woodland is still periodically burned with resulting damage to timber and destruction of litter and humus.

CONDITION OF LAND OTHER THAN FOREST

The improved lands occupy about 50 per cent of the area. Corn is the prevailing cultivated crop. Erosion from corn lands could be reduced by contour plowing, and there are also some sites which could be terraced. At times certain soils on this basin have suffered very greatly from drought. Terracing, which insures the holding of water which otherwise would run off the surface, tends to lessen the liability to drought. The majority of the lands on this basin do not sod to bluegrass as do the lands north of the Missouri River. The orchard grass grows well on drier sites and red top on moist sites. Orchard grass, however, does not give the same protection to soil as a well established mat of bluegrass sod, and there is more erosion where orchard grass is used.

CONDITION OF FOREST

Forest lands are of two kinds. Pine occupies a large area at the northeastern part of Texas County along Big Piney Creek, and there are some smaller areas in other places. The prevailing forest, however, is upland-type hardwood. The lowland-type hardwoods which occupy the low lands along the streams have largely been cut and these lands cleared and placed in cultivation. Some of the lowland subject to excessive overflow is in grass, and extremely small areas still remain in timber, and such areas are becoming more restricted as time passes.

EFFECT OF LUMBERING

There are two general classes of lumbering—the large operations chiefly confined to the stands of pine in the northeastern part of Texas County and the operations which are conducted by farmers and small mills. The farmers' operations at present are largely

restricted to cutting ties. At one time this was an extensive industry, the ties being rafted down the streams and eventually sold at St. Louis. At the present time, with the aid of trucks, they are usually hauled to the railroad. The pine lands, after being cut over, have usually been severely burned. They were cut very close, only a few small pine trees were left, and in places there is a decided deficiency in young pine on account of the lack of seed trees and the destruction of seedlings by fire. This is at the extreme northern limit of shortleaf pine, to the west of the Mississippi River.

EFFECT OF FIRES

Fires after lumbering result in the suppression of young growth as well as in injury to the butts of larger trees. Such injury causes permanent defects which increase by extending up the stems of the trees as they become older. In many places the fires have tended to decrease the proportion of pine and to increase the number of hardwoods, which sprout more freely.

EFFECT OF GRAZING

The destruction of tree seedlings and extermination of forest herbage by close grazing has resulted in excessive erosion in woodland. Likewise, close grazing in pastures has resulted in much erosion from this class of land.

EFFECT OF DRAINAGE

Except for narrow areas of alluvial land there are no extensive areas of swamp lands on the basis of this stream. These lands have been drained largely by individual farmers as there are no large drainage projects. The alluvial lands are now largely cleared and constitute the best type of agricultural land on the basin. Their drainage may have tended to promote higher flood crests on the lower part of the basin through facilitating run-off.

GENERAL SUMMARY OF FOREST CONDITIONS

On the whole, the forest conditions on the basin are not satisfactory. Pine is the most valuable saw-log tree and pine lands are being cut too closely because the trees can be profitably utilized to a very small size. Where there are fires and where fires follow lumbering, pine replacement is frequently very scant. The hardwoods which constitute the larger part of the forest are deteriorating through the constant culling of the choicest species, white oak and walnut. As a result the less valuable black and blackjack oak are increasing in numbers. The soil conditions also are much below a desirable standard. On account of frequent fires, humus is either scant or almost wanting, and this results in a lowered absorptive capacity by the mineral soil and a reduced storage capacity for storm water.

Protective value of watershed

[Area of basin 2,266,000 acres or 3,540 square miles]

RATINGS

Class	Area		Unit protective value	Proportionate protective value	Protective rating
	Acres	Per cent			
Soil:					
Silty and stony	2, 081, 000	92	0. 75	0. 69	
Alluvials	185, 000	8	. 90	. 072	
					0. 762
Topography:					
Very hilly	906, 000	40	. 50	. 20	
Rolling and level	1, 360, 000	60	. 85	. 51	
					. 71
Precipitation: Rainfall	2, 266, 000	100	. 90	. 90	. 90
Character of cover:					
Pine and hardwood	1, 148, 000	51	. 75	. 382	
Grass	544, 000	24	. 90	. 216	
Corn	283, 000	12	. 50	. 0600	
Small grain	291, 000	13	. 75	. 0975	
					. 75
Average					. 78

FOREST COVER

About 19 per cent of the area is in forest cover. Since nearly all of the woodland is on steep land and is used for woodland pasturage, it has a low protective value because of excessive grazing.

CRITICAL AREAS

The critical areas within this basin consist of the bluffs and breaks along the streams, especially where the slopes are in excess of 5 per cent and where the soils are silty. The critical areas occupy practically 40 per cent of the area of the basin. They include the greater portion of the land which is at present wooded. In addition they include a considerable area of steep land which has been cleared and which is at present in grass occupying the steeper slopes adjacent to the streams.

RECOMMENDATIONS

A greater part of the larger bodies of forested lands on this basin should be set aside as public forests. This would extend protection to a large part of the critical area within the basin. Part of this land is at present in tracts of considerable size held by lumber companies, but the larger portion of it is woodland on the rougher portions of farms. In the northern part of the basin, on account of the fact that farms are generally interspersed with this land and occupy nearly all of the alluvials and a considerable part of the hilly uplands, these conditions do not meet the requirements for national forests but are admirably suited for the location of State and county forest. In the southern and especially the southeastern part of the basin there are areas which, taken in connection with lands on the basin of other streams, are admirably suited for the location of national forests.

On the whole, the erosion problem of this basin is not so acute as on the loess soils on the north side of the Missouri River, but erosion still takes place. The important function of these forests will be the affording of better protection to the soil and the promoting of more thorough absorption of heavy concentrated showers. The accumulation of humus will supplement the storage capacity of the soil to the extent that humus can be developed within these forest types.

A great advantage will likewise accrue to the landowners. Throughout this basin the small farmers have worked in the woods during that part of the year when there was little farm work to be done. The maintenance of the forest on a high producing capacity will permit a continuation of this advantageous practice. The manufacture of ties offers opportunity to the small farmer for winter work. At the present time most of the pine timber has been cut from the basin and on account of close cutting and fires timber suitable for ties has been largely depleted.

Woodland pasturage should also be more carefully controlled in order to prevent deterioration of the range and reduce erosion, since a large part of such pasturage is located upon the steep slopes which are easily eroded. This and the prevention of fires are the desirable changes necessary in wood policy. In the northern part of the basin Federal action may be desirable in the extension of protection against fire through the cooperative provisions of the Clark-McNary Act. The larger areas of land in the southern part of the basin should become a part of national forests, occupying considerable additional areas of rough land on other parts of the Ozark Plateau.

STREAM CONDITIONS

The Central Missouri Power & Water Co. has preliminary permits from the Federal Power Commission for the construction of three hydroelectric plants between Jerome and Richfountain the total capacity of which will be about 100,000 horsepower. On account of the hilly surface and the width of the upper part of the basin, quite heavy floods occur at times; but, since the flood plain is quite narrow, not much damage is caused. The flow of the stream is kept fairly constant by numerous large springs. The run-off varies from 6.73 inches to 11.35 inches for the 5-year period of measurements. The extremes of flow varied from a maximum stage, 17.5 feet, during June, 1921, with a discharge of 25,900 second-feet, to a minimum discharge of 77 second-feet in September, 1922, or a ratio of 1 to 336. In August 1915, the river reached a stage of 25 feet with an estimated discharge of 45,000 second-feet.

GRAND RIVER

(Area 64)

LOCATION AND AREA

The Grand River is a comparatively small tributary coming in from the north and flowing into the Missouri about 200 miles above its mouth. Its basin, lying partly in southern Iowa and partly in

northern Missouri, has a drainage area of 7,831 square miles. It is formed by the union of the east and west forks and has for its principal tributaries the Thompson River and Medicine and Locust Creeks.

TOPOGRAPHY

The drainage basin is about 150 miles long. Very narrow at the upper end, it gradually widens to 90 miles near the middle, and decreases to a narrow strip at the mouth. The shape of the basin and the rolling surface of its upper part is conducive to heavy floods, the water of the several converging tributaries emptying nearly simultaneously. The surface of the upper part of the basin is rolling, broken in places to rather steep hills, but the tops of the ridges form nearly a flat plain near the mouth. The channels of the river and its tributaries were naturally crooked. In the upper part of the river the channels of some of the tributaries have been improved by straightening and dredging and this has given partial relief from floods in those places, but by bringing the water more quickly to the lower reaches of the river it has intensified the flooding in that section. Much more work needs to be done in order to protect the lower valley from overflow.

GEOLOGY AND SOIL

The basic geological formations have little influence upon the upland soils of the Grand River Basin which are largely from two sources of unconsolidated material. The limestone, shale, and sandstone formations of the Carboniferous age which form the basic rocks of the region are covered with the glacial mantle known as Kansas drift, a deposit which varies from a few to many feet in thickness and is characterized by the presence of clays, sands, and stones. The Kansas drift was subsequently covered by a layer of loess, fine grained silts, and sand silts deposited by wind action from areas of similar soils located elsewhere. On the shoulders of the hills the loess has been removed, exposing the underlying glacial drift. The alluvial deposits along Grand River are largely an outwash from these soils. The river hills are prevailingly red, silt-clay lands. They form a belt which varies in width from one-half to 4 miles, and lies just back of the river bottoms. Owing to its open structure and rolling surface, the soil of the river hills is easily drained and has been largely cleared. Because of this loose structure of soil and subsoil and the usually sloping surface erosion is often severe. "Gullies formed are usually deep with perpendicular walls exhibiting a checked and columnar structure peculiar to loess." Cuts of this character, 15 to 30 feet deep are common, and as a safeguard against erosion this soil should never be left in a loose or uncovered condition. The greater part of the level uplands, which were originally prairies, do not suffer from erosion, but the rolling lands in the northern part of the basin are subject to erosion, the amount varying with the degree of slope.

CLIMATE

The mean precipitation varies from 39 inches on the lower part of the basin to about 37 inches on the upper part, the unmelted snowfall averaging about 30 inches. The periods of heavy rainfall are from April to July. In the wet year of 1898 when the total rainfall amounted to more than 60 inches, as much as 11.88 inches fell during May. The amount of rainfall for the driest year of record was 19 inches. Though droughts of over three weeks' duration are rare and the basin is considered outside of the southern region of concentrated precipitation, an average of 50 heavy thunderstorms a year occur and it is when these are accompanied by heavy rainfall that excessive erosion takes place.

HISTORICAL DEVELOPMENT

The initial settlements on this basin were made about 1837. The pioneers came from forested States, and located largely on the wooded lands not only on account of their ignorance of the quality of the prairie soils but because of the presence of springs, and the ability to get water was limited to the more hilly lands. Large areas of the woodland were thus cleared in the early stages of the development of the basin. The first crops were largely corn. Although no longer commercially produced, tobacco was one of the early money crops because of the ease with which it could be transported. A large part of the basin is still cultivated in corn, planted in rotation, or in corn following corn. A considerable area is cultivated in soy beans and a smaller area in tobacco and other clean tilled crops, all of which offer the same opportunity for excessive erosion as is offered by corn. A large area of the land especially in the upper part of the basin is maintained in sod from which the erosion is very slight where not excessively pastured, as is frequently the case on woodland pasture. The present population of the basin is approximately 35 per square mile outside of towns. The total area of the basin is 5,012,000 acres; the improved area is 4,431,000 acres or 88.4 per cent, the area in woodland being 581,000 acres or 11.6 per cent of the total area.

CONDITION OF LANDS OTHER THAN FOREST

A considerable area of the basin is in sod and is so maintained either for grazing or for hay. A large part is devoted to cultivated crops, and because of the superior drainage condition the rolling lands are given preference. In too many instances instead of land being cultivated two years and then seeded to grass, cultivation of corn followed by a crop of small grain is succeeded again by a crop of corn, or corn follows corn without the alternation of a small-grain crop. As a rule, land from which small grain is taken in the summer is turned the following fall and left without cover crop for seeding to corn the succeeding spring. The drainage of the alluvial lands, especially in the upper part of the basin, has been largely effected through deepening and straightening the channels of the streams. This has resulted in accelerating the run-off from this portion of the basin and, by simultaneously precipitating flood waters from the different streams, has added to floods in the lower part of the basin and rendered the alluvial lands in that portion less valuable.

CONDITION OF FOREST

Two types of forest existed, the upland hardwood type, the matrix of oak associated with hickory, elm, walnut; and the alluvial swamp type, composed largely of cottonwood, elm, ash, and pin oak. The upland forests in this basin, which originally occupied about one-half of its area, were limited to the river hills forested with elm, walnut, hickory, sugar maple, and various oaks; while the rolling hills and the slopes along the smaller streams in the northern part of the basin were covered by a similar forest growth containing a larger proportion of oak and hickory. The remainder of the basin was either unforested prairies or oak openings dotted with scattered trees.

While there has been no general lumbering on a large scale, most of the original timber has been cut. At the present time only occasional groves are left, these being on the steeper banks or held by a careful farmer. Most of these groves, however, are so closely grazed that there is a great deficiency in protective soil cover, and constant and excessive erosion is taking place. It is not uncommon for the roots of the trees to be exposed over much of the surface. This is due to overgrazing, which results in denudation of soil and produces conditions under which constant surface erosion takes place.

Except for a fringe of elm, cottonwood, and similar trees along some of the streams, the forests on the alluvial soils have been almost entirely removed. The upland type of forest has been largely removed except on steep bluffs and hills. This is true especially in the northern part of the basin. Nearly all of the woodland is closely pastured and much of it shows signs of continued sheet erosion. The resulting insidious depletion of soil and steady contribution of silt to the stream channels has in part necessitated the dredging and drainage work which has been done. The protective value of the watershed is rated as follows:

Eighty per cent of the area consists of silt soils which, unless level, are subject to excessive erosion. Twenty per cent consists of soils less subject to erosion. Of the open surface 50 per cent consists of level or very gently rolling areas, and has a protective factor of 90. Forty-five per cent has a protective factor of 60. Five per cent (the bluffs and hills) has a protective factor of 50. The precipitation, essentially uniform over the entire basin, is of an advantageous nature, resulting from a moderate amount of snowfall, a rainfall evenly distributed during the year and only moderate in amount, and an absence for the most part of a concentrated rainfall.

(A) Lumbering has had no injurious effects upon stream flow.

(B) Fire is not a factor influencing forest conditions on this basin.

(C) Grazing of woodland is excessive and does much to increase erosion.

(D) The drainage of minor streams, by accelerating run-off from the upper parts of the basin, has had the effect of increasing floods on their lower reaches.

(E) The woodland on this basin consists chiefly of wood lots which are parts of farms located on the steeper lands along the streams and river bluffs. There is no extension of the forest area either through planting or through natural replacement. Natural replacement in general is scant, the result of excessive grazing and

of the soil deterioration which follows. A few windbreaks have been established on the level prairie parts of the northern part of the basin.

Protective value of watershed

[Area of basin, 5,012,000 acres, or 7,831 square miles]

RATINGS

Class	Area		Unit protective value	Proportionate protective value
	Acres	*Per cent*		
Soil:				
Silty	4,016,000	80	0.50	0.40
Clayey	996,000	20	.75	.15
				.55
Topography:				
Hilly	2,506,000	50	.50	.25
Rolling and level	2,506,000	50	.75	.375
				.625
Precipitation	5,012,000	100	.75	.75
Character of cover:				
Forest	584,000	12	.70	.084
Grass for hay	677,000	13	1.00	.13
Grass for grazing	1,792,000	36	.75	.27
Corn	1,169,000	23	.50	.115
Small grain	790,000	16	.75	.12
				.719
Average				.661

FOREST COVER

Ten per cent of the area is in forest cover with a low protective factor the result of excessive grazing. Ninety per cent of the area is nonforested. Deficiency of cover crops in winter and the cultivation of clean crops such as corn give it a low protective factor.

CRITICAL AREAS

Critical areas within this basin are the bluffs and steep slopes. The soils of the slopes, derived from loess, are subject to excessive erosion wherever exposed to rainfall. A large part of these steeper areas which are at present cleared can be maintained as farming land if kept in grass and not subject to excessive tramping of stock. Certain areas, however, can have their protective efficiency maintained only through the reestablishment of forests, or through cessation or curtailment of woods grazing. The protection of these critical areas will reduce the amount of silt going into the Missouri River and will tend to maintain the productivity and value of the alluvial lands, especially in the lower part of the basin. It will also protect the water-power interests in the event that reservoirs are located upon this basin.

RECOMMENDATIONS

Some of the wooded bluff lands are of sufficient area to justify setting them aside as small public forests. There are certain other steep slopes which might be acquired as small public parks. This would extend protection to these areas. The areas suitable for public forests are not of such extent as to come within the scope of the purchase work being conducted by the National Forest Reservation Commission in acquiring forest lands for the Federal Government, nor should it be necessary for the commission to extend its work to such relatively small tracts. They would, however, fit in admirably with a well-planned system of state-owned forest. The same may be said of the public park areas. They do not meet the standards set up for national parks but would be of great value and service as State and local parks and playgrounds. On the whole, however, the problem of erosion in this basin is one of better agricultural practice. This will not only be of benefit in lessening the contamination of the streams but will be advantageous to the landowners in maintaining on a higher basis the permanent productivity of their lands. The greater advantage will accrue to the landowners. The present excessive erosion is indicative of faulty agricultural practice which primarily should be corrected with a view to maintaining the productivity of the most important basic asset of the States. The pasturage of woodland should be controlled more carefully in order to prevent deterioration of the range and to reduce erosion, since a large part of the pasture land is located upon the steep slopes with loess soil, which is especially prone to erosion. This likewise is a factor which should receive the most careful consideration of the States involved. Notwithstanding the fact that bluegrass forms an excellent sod which very largely prevents erosion, there are certain areas so steep that it is a jeopard to their permanent fertility to graze them. These areas were originally wooded slopes and it is desirable that they should again be wooded, not primarily to reduce the silt burden of the streams but for the purpose of maintaining the permanence of the soil itself.

Contour plowing should be more largely practiced and at the same time it should be the custom on the steeper land to "lay by" corn, even when checked, by letting the last cultivation follow the general direction of the contours. Certain other lands could well be terraced, the steepest lands in level step terraces, which will absolutely prevent any run-off, and hold all the precipitation for the benefit of the crop. The rolling lands could be terraced with a Magnum dike which can be cultivated across without lessening the tillable area of the field. These are practices which the county agents will naturally urge as a matter of soil use and stabilization. Extension work in this region may make a material contribution toward flood prevention if the county agents are selected with special reference to a knowledge of the value of steep lands and stream margins for timber production and the evil consequence of soil erosion.

The area does not involve a fire problem of any consequence. Forest areas are too limited in extent and wood too valuable for fire to be allowed to run at large. The inflammability is not great

and the protection received from resident owners is usually adequate. Unless the State assembles larger areas for forest purposes and under better management a more intensive system of fire control appears unnecessary. There does not seem to be any need for extending special aid to this region under the fire-cooperative features of the Clarke-McNary law.

Federal action desirable on this drainage, therefore, seems to be limited to extension work through the county agents and other mediums of extension.

STREAM-FLOW CONDITIONS

Especially disastrous floods occurred in 1909, 1915, 1922, and 1926. The discharge varied from 170 second-feet (January, 1925) to 56,400 second-feet (September 21, 1926); the corresponding water stages being 2.8 feet and 32.42 feet. As determined by flood marks, the river reached a stage of 36.7 feet on July 9, 1909, prior to the establishment of a recording station. The run-off for the two years for which data are available was 4.78 inches a year (or 0.352 second-feet per square mile a year) for the years 1924–25, a period of low rainfall, and 11.42 inches a year (0.840 second-feet per square mile a year) for the period 1925–26. The stream, which has an elevation of about 900 feet at its mouth, is bordered by a comparatively wide flood plain having rather low hills rising 200 or 300 feet in rather steep slopes from the flood plain to the general surface level of the basin. No data are available as to the possibilities of storage reservoirs upon this basin. Stream measurements have been secured for several years at two points on the basin. There is some possibility of water storage for power purposes. The city of Trenton secures its domestic water supply from Thompson River.

The area of the Grand River Basin is 5,011,840 acres, of which approximately 31 per cent has a slope in excess of 4 per cent. Some of this has a much steeper gradient and slope, in places running up to as high as 20 per cent on the hills and bluffs which face the streams. The wooded land is chiefly, though not exclusively, on this class of slope. Sixty-nine per cent of the basin has a slope which averages about 120 feet to the mile or a gradient of about 2 per cent.

A slope of 3.68 per cent upon the prevailing soil type of northern Missouri has been found to result in a soil loss of 3.27 tons per acre from erosion during one year from land in corn and wheat in rotation; 25.26 tons from land continuously in corn; and 0.24 tons from land in sod.

Since the velocity of water on a slope varies with the head, 3.68 per cent gradient has a theoretical velocity of 15.2, while a 2 per cent gradient would have a velocity of 11.5, and a 4 per cent gradient would have a theoretical velocity of 17 feet per second. The capacity for the transportation of silt (capacity for erosion of soil) varies as the square root of the fifth power of the velocity. Consequently the silt-carrying capacities of streams of water flowing over land having these respective gradients varies as 448 to 871 to 1,191 or as 0.5; 1; 1.37.

Employing this figure (871) as a base, the tendency of the same soils on slopes having gradients of 2 per cent and 4 per cent when in the same crops is shown in the table which follows:

Average annual erosion of silt loam soils of northern Missouri under different degrees of slope in different crops

Kind of crop	Tons of earth eroded per acre a year from a slope of—		
	2 per cent	3.68 per cent [1]	4.2 per cent
Corn in rotation with small grain or sod	1. 63	3. 27	4. 47
Corn following corn	12. 63	25. 26	34. 60
Soy beans or cotton	10. 05	21. 00	28. 77
Grass or clover	. 12	. 24	. 33

[1] Experiments covering 7 years conducted by Dr. F. L. Duley and Mr. M. F. Miller, in northern Missouri.

Approximate area in different crops. Rate of erosion and total amount of soil eroded

Crop	Acres	Site with slope of 4 per cent or over	
		Rate of erosion per year	Amount eroded per year
		Tons	*Tons*
Corn	363, 960	4. 47	1, 626, 900
Grass	627, 900	. 33	207, 000
		Site with slope averaging 2 per cent	
Corn	293, 000	12. 63	3, 700, 000
Small grain	1, 674, 000	1. 63	2, 729, 000
Grass	1, 589, 000	. 12	190, 000
			8, 452, 900

Although the area of the Grand River Basin is only about 1.5 per cent of the total area of the Missouri River drainage, it appears to contribute essentially 5 per cent of the silt burden of the entire river. This burden is clearly excessive and has been enormously augmented as a result of the extension of the cultivated area and injudicious methods of tillage.

THE MISSOURI (DIRECT—IN MISSOURI)

(Area 66)

LOCATION OF AREA

Five rivers varying in length from 60 to 100 miles flow into the Missouri River in the 400 miles from southwestern Iowa to its mouth. Their basins lie partly in northwestern Missouri and in western Iowa, the headwaters of the most westerly streams being located in middle Iowa. These streams have a total drainage area within the State of Missouri of about 16,047 square miles. Beginning at the south and proceeding north the chief streams are the Platte,

Loutre, Little Charlton, Crooked, Fishing, Nodaway, Tarkio, and Nishnabotna Rivers. In addition there are a number of creeks occupying drainage basins between these rivers which flow directly into the Missouri. The areas of these are included, as well as the area of the Blackwater River coming in on the west side.

TOPOGRAPHY

These streams have basins, surface conditions, soil, and rainfall so nearly alike that they can be considered and described as a unit, although progressing northward there is a gradual change in surface, soil, and climate. The drainage basins vary from 70 to 120 miles in length. All are narrow at the upper end and all maintain narrow basins to their mouths, having only a few almost parallel lateral tributaries. Their surface consists of about 20 per cent level alluvial lands and about 80 per cent upland. The upland, as a rule, is a dissected plain which once sloped very gently from the northwest to the southeast. These numerous streams have cut back into this plain so that the only remnants of this level upland are the crests of the ridges which separate the small drainage systems. The elevation of these ridges at the extreme north is about 1,200 feet, and those at the south within Missouri vary from 1,000 to 1,100 feet. The surface of the higher parts of these divides is gently undulating. It becomes steeper and more broken as the main streams are approached. Along the main streams and the large tributaries the slopes are often steep and sharp, and sometimes there are rock outcrops and low ledges, especially to the southward. The unevenness of the surface increases as the bluff line bordering the Missouri River flood plain is approached. On the southern streams this bluff line rises from a base elevation of about 760 feet along the bottom lands of the Misouri River to over 1,000 feet in a distance of from one-quarter to one-half mile. For the northern streams it rises from a base level of about 1,000 feet to bluff crests of 1,200 feet. As a rule the surface for a distance of several miles back from the bluff is so thoroughly dissected that it presents a succession of steep hills and intervening hollows. The surface back from the river, when viewed from a distance, presents a rounded billowy appearance. To the east farther from the river there are broad stretches of level or gently rolling prairies.

The channel of the Missouri River is constantly changing its position and has so frequently made cut-offs since it was established as the boundary line between Missouri on the east and Kansas and Nebraska on the west that at a number of points it has left portions of Missouri and Iowa on the west side of the river and portions of Kansas and Nebraska on the east side. The channels of the tributary streams were naturally crooked. Nearly all these have been improved by straightening and dredging. This has as a rule given relief from floods to which the alluvial lands on the lower part of the basin were especially subjected.

GEOLOGY AND SOIL

The upland soils upon the basins of these streams are derived from a single source of unconsolidated material, and are little influenced by the basic geological deposits. The limestone, shale, and sandstone

formations of the Pennsylvanian system of the carboniferous age which form the basic rocks are covered with a glacial mantle known as the "Kansas Drift." This deposit varies from a few to many feet in thickness. It is composed of deposits of clays, sands, and gravels derived in part from the underlying rock and in part transported from the north during the ice age. This drift was covered along the western edge with a silty loessal layer deposited either by wind or water action and supposed to have been derived from the Missouri River. It skirts that stream and is deepest near the river, gradually thinning out at a distance from 50 to 70 miles to the east. This glacial material forms a large part of the soil on the upper headwaters of the stream basins. The alluvial deposits along these smaller tributaries are largely an outwash from these soils, but the deposits in the broad bottoms of the Missouri have been brought down that stream partly from its headwaters.

The river hills consist of dark-colored silts. Owing to continuous cultivation these in many places have been subject to severe washing, which has sometimes resulted in the formation of destructive gullies. Numerous brown spots or galled areas also occur along the more rolling slopes where the surface soil is badly eroded, leaving the subsoil exposed. Since soil material of this type at any depth below the surface may be made almost as productive as the surface soil by adding decaying vegetable matter or by turning under barnyard manure or a green crop, the productiveness of these eroded spots may be greatly improved. This situation also leads the owners of these lands to be negligent of preventing erosion. In places, however, the loessal drift is shallow and, where it is removed, the less productive glacial deposits are exposed. Erosion is the most serious problem interfering with permanent profitable farming on these lands. To the eastward the rolling and level lands in part consist of black silty soils which were largely prairie and not susceptible to excessive erosion, and in part of clay soils. These as a rule are so situated that they do not erode destructively.

CLIMATE

The mean annual precipitation varies from 37 inches on the lower part of the basin to 35 inches on the streams at the northern end. This precipitation is very light during the winter and heaviest in midsummer. Two-thirds falls during June, July, and August, the season when the soils are in cultivation. The lower part of the region is within the area of heavy thunderstorms which average 50 to a season. This condition is conducive to concentrated rainfall and erosion of soil during the summer. Thunderstorms rapidly decrease toward the north, numbering only about 40 per season. There is also a material difference in the length of the winter and the amount of snowfall toward the north, the winter being longer and the snowfall heavier. Longer winters and frozen soils are inimicable to erosion.

HISTORICAL DEVELOPMENT

The initial settlements on this basin were made about 1835 in northeastern Misssouri. The streams farther west were settled at progressively later dates. The settlements in Missouri were largely

made by pioneers from the older forested States, who selected by preference the wooded lands on the river hills, because they were considered most fertile and because of the presence of springs. It thus followed that a large part of the woodland in this portion of the area was cleared at an early date. Over most of the region to the north there was practically no native timber except on the bluffs along the streams.

The lands farther north in Iowa were largely settled by foreigners, who as a rule selected the open prairies. The hilly lands which were the areas chiefly covered by woods were largely ignored on account of the broken surface. Tobacco as well as corn is one of the chief crops produced on the hilly lands of the streams in northwestern Missouri. Both of them are cleanly cultivated crops, presenting conditions for excessive erosion. Much of the land, however, even in this section is in grass and considerable small grain is produced. Orchards and vineyards occur on some of the bluff lands bordering the Missouri River, and this class of farming extends along the hills up the larger streams. This is a desirable condition, since this land, even when well tilled during the summer, is protected by cover crops during the winter, spring, and fall. This largely reduces the period to which it is exposed to erosion. Although corn has always been the important crop, a large proportion of the tilled land is in small grain, and a large proportion of all cultivated land, especially on the slopes, is in grass, clover, and alfalfa. The total area of land reported as improved is 8,787,280 acres, or 80.8 per cent; the area of forest is 1.526,000 acres; of woodland, 568,000 acres; a total wooded area of 2,094,000 acres, or 27.1 per cent of woodland. At the present time the population of these basins is approximately 30 per square mile for the rural region. Throughout this area, wherever silt soils occur on slopes, they require careful cultivation and need to be kept in cover crops as much of the time as possible in order to prevent erosion. Many farmers keep the draws and drainage areas in grass with this purpose in mind. Where the surface soil has eroded away or has become very thin, as on many of the steeper slopes, the surface material greatly needs organic matter. The best farmers make it a practice to apply large quantities of barnyard manure in these places annually. In the southern part, owing to continuous cultivation, the rolling and hilly silt types of soil are in many places subject to severe washing, which sometimes results in the formation of destructive gullies. This is particularly notable in Nodaway County, Mo., and in the adjoining counties to the north and south.

CONDITION OF LANDS OTHER THAN FOREST

The lands in the basins of these streams are essentially in the same condition as those of the Grand River, which is located in the midst of the area under consideration. What has been stated for that basin in regard to the methods of cultivation, the proportion of land in sod, and the proportion of small grain cultivated, applies without change to the basins under consideration.

CONDITION OF FOREST

Two types existed in the original forest—the upland hardwood type, largely oak associated with hickory and walnut, particularly on the bluffs and slopes, and the alluvial swamp type, largely of cottonwood, elm, ash, and pin oak. The upland forests which originally occupied more than one-half of the area covered the river hills and slopes along the streams, and the more level lands, especially at the west end of the basin, were either nonforested prairies, or were dotted with open grooves of scattered trees.

Though there has been no general lumbering, most of the original timber has been cut. Only occasional groves are left at the present time on steep slopes or where they have been preserved by their prudent landowners. The original woods contained large amounts of walnut. When the demand for walnut died out in the nineties much of it had been removed but many young groves persisted. In the course of two decades many of these trees reached merchantable size. After a period of a quarter of a century during which there was no demand for walnut lumber, it came into demand to supply gunstocks and a revival in the fashion for walnut furniture. There has followed during the past 12 years extensive cutting on the slopes throughout this region, not only of walnut but also of a large amount of the best oak and other timber. The removal of this timber has been accelerated during the past few years by the low price of farm products, and landowners have been forced to draw heavily upon the small and meager reserve of timber. The forests on the alluvial soils have been almost entirely removed except for a fringe along the streams and for small bodies on the wetter sites or low places subject to periodic overflow. There is a notable absence of young timber in practically all of these stands due to close pasturage.

Nearly all the woodland shows signs of excessive sheet erosion, resulting in constant depletion of soil and an increased burden of silt to the streams. This condition has in part necessitated extensive dredging and drainage work (still in progress) to protect the alluvial lands. The protective value of the watershed is rated as follows: 90 per cent is silt soil subject to excessive erosion wherever denuded; about 10 per cent consists of soil less subject to erosion; 40 per cent is level or gently rolling with a protective factor of 90; 30 per cent has a protective factor of 60; while 30 per cent consists of the bluffs and breaks along the Missouri River and the tributary streams with a protective factor of 50. The average protective factor is 69. Regarding 50 as a most serious condition, this represents an area subject to most deleterious erosion.

It is estimated that on an average these streams annually contribute in excess of 16,000,000 tons of soil to the water of the Missouri River. More than two-thirds of this comes from corn and other cleanly tilled crops which are grown on land having slopes in excess of 2 per cent gradient. Only a small amount is derived from the hay lands, but a considerable portion comes from the grazing lands. Where woodland is excessively pastured it yields relatively a large amount of silt for wooded land, though a small amount in the aggregate. There is a small area on the south side of the river where the

soils are derived from shale and where erosion is less active than from the silty loess soils which occupy by far the greater portion of the surface on the basin. All of the area, however, which has a slope of 3.6 per cent or more can be regarded as within the critical limits. This includes a large part of the river hills.

A. Lumbering has had no injurious effects upon the woodland of these basins.

B. Fire has had no injurious effects upon the woods.

C. Grazing has seriously impaired the protective value of nearly all woods on this basin and has tended to increase flood crests.

D. Drainage of valley lands has increased the rapidity of run-off and increased flood crests on small streams.

E. Although originally about 40 per cent of this entire area was in forest, this proportion has now been very greatly reduced. At the present time the forest is limited to farm wood lots located chiefly upon the steeper land on the rougher hills along the smaller streams, and on the bluffs and breaks along the Missouri. The condition of this land is far from satisfactory, although fire is not a factor. The almost universal use of woodland for pasturage and for stock lots has resulted not only in preventing replacement, so that the woods are chiefly mere open groves, but also has been followed by a great deterioration in all classes of ground cover accompanied by exposure of soil, erosion, and soil deterioration.

Protective value of watershed

[Area of basin 10,880,000 acres or 17,000 square miles, in Missouri and Iowa]

RATINGS

Class	Area		Unit protective value	Proportionate protective value
	Acres	Per cent		
Soil:				
Silt	9,792,000	90	0.50	
Clays and alluvials	1,088,000	10	.75	0.52
Topography:				
Steep hills and bluffs	3,264,000	30	.50	
Hilly	3,264,000	30	.60	
Rolling and level	4,352,000	40	.90	.69
Precipitation: Rainfall	10,880,000	100	.75	.75
Cover:				
Forest	2,067,000	19	.70	
Hay grass	1,114,000	9	.90	
Grazing land	3,388,000	31	.75	
Corn	2,245,000	21	.50	
Small grain	2,051,000	20	.75	.70
Average				.67

FOREST COVER

Nineteen per cent of the area is woods, with a protective factor of 60, caused by excessive grazing. Eighty-one per cent of the area is nonforested, with a protective factor of 63, caused by deficiency to cover crops in winter and the large proportion of cleanly tilled land. The average protective factor of cover is 0.67. The forest is entirely hardwood.

CRITICAL AREAS

The critical areas include the bluffs and steep slopes with soils derived from loess. These are subject to excessive erosion whenever they are denuded and exposed to rainfall. A large part of these steeper areas are cleared at present and can be maintained as farming land if kept in grass and if excessive grazing is avoided. A considerable part of the critical areas are on slopes too steep to use for cultivated crops. Some of them are so steep that hay crops can not economically be gathered therefrom. The protection of certain of the steep lands can be maintained only through the reestablishment of forests or through cessation or curtailment of woods grazing.

RECOMMENDATIONS

Some of the wooded bluff lands are of sufficient area to justify setting them aside as small public forests; there are certain other steep slopes which might be acquired as small public parks. This would extend protection to these areas. The areas suitable for public forests are not of such extent as to come within the scope of the purchase work being conducted by the National Forest Reservation Commission in acquiring forest lands for the Federal Government; and it should not be necessary for the commission to extend its work to such relatively small tracts. They would, however, fit in admirably with a well-planned system of State-owned forests. The same may be said of the public park areas. They do not meet the standards set up for national parks but would be of great value and service as State and local parks and playgrounds.

On the whole, however, the problem of erosion in this basin is one of better agricultural practice. This not only will be of benefit in lessening the contamination of the streams but also will be advantageous to the landowners in maintaining the permanent productivity of their lands on a higher level. The present excessive erosion is indicative of faulty agricultural practice which primarily should be corrected with a view to maintaining the productivity of the most important basic asset of the area. The pasturage of woodland also should be more carefully controlled to prevent deterioration of the range and at the same time reduce erosion, since a large part of the woodland pastures are located upon the steep slopes bearing loess soil. Notwithstanding the fact that bluegrass forms an excellent sod which very largely prevents erosion, there are certain areas so steep that it is a jeopard to their permanent fertility to graze them. These areas were originally wooded slopes and it is desirable that they should again be wooded, not only to reduce the silt burden of the streams but also to maintain the permanence of the soil itself.

Contour plowing should be more largely practiced and at the same time it should be the custom on the steeper land to " lay by " corn, even when checked, by letting the last cultivation follow the general direction of the contours. Certain other lands could well be terraced; the steepest lands in level step terraces, which prevent run-off and hold all the precipitation for the benefit of the crop, and the more rolling lands terraced with Mangum dike which can be cultivated

across without lessening the tillable area of the field. These are practices which the county agents will naturally urge as a matter of soil use and stabilization. Extension work in this region can make a material contribution toward flood prevention by the selection of county agents with special reference to knowledge of the value of steep lands and stream margins for timber production and the evil consequences of soil erosion.

The area does not involve a fire problem of any consequence. Forest areas are too limited in extent and wood too valuable to allow fire to run at large. The fire hazard is not great and the protection received from resident owners is usually adequate. Unless the State assembles larger areas for forest purposes, a more intensive system of fire control appears unnecessary. There does not seem to be any need for extending special aid to this region under the fire-cooperative features of the Clarke-McNary law.

Federal action desirable on this drainage, therefore, seems to be limited to extension work through the county agents and other mediums of extension.

STREAM-FLOW CONDITIONS

The Nishnabotna River, with a length of about 100 miles and a drainage area of 2,920 square miles, shows a maximum stage record of 16.65 feet in April, 1922 (discharge 11,800 second-feet), and a minimum stage of 2.40 feet in February, 1923 (discharge 165 second-feet).

The Tarkio River with a drainage basin 80 miles long, has a drainage area of 721 square miles. It is very narrow at the upper end, widens to 15 miles in the lower half, and then decreases to about 2 miles near its mouth. The range in the flow of this stream is large. Loss of crops formerly occurred frequently before the channel was straightened and deepened. The maximum stage recorded is 91.3 feet in September, 1926, with a discharge of 7,940 second-feet. The minimum discharge was 1 second-foot in December, 1924.

The Nodaway has a drainage basin 110 miles long. It is very narrow at the upper end, widens to 30 miles about the middle, and then quickly decreases to 12 miles. The drainage area is 1,780 miles. The flow of the river fluctuates widely, there being a heavy run after hard rains. Straightening the channel has given some relief from floods. The maximum stage recorded is 18.65 feet in September, 1926, with a discharge of 16,100 second-feet. The minimum stage was 1.80 in July, 1923, with a minimum discharge of 6 second-feet.

Platte River with a total length of 183 miles has a drainage basin 130 miles in length and containing 2,440 square miles. Its basin has an average width of about 20 miles and at no point is more than 28 miles wide. As in the case of the streams farther north, the flow fluctuates widely. Large overflows occur and result in much damage to crops and other property, notwithstanding partial relief from straightening and deepening the channel. Especially disastrous floods occurred in July, 1915, and in September, 1926. The latter flood caused damage in the valley estimated at more than $500,000. Much work still needs to be done in the basin before the rather frequent and large losses from floods can be eliminated. No data are

available on the possibilities of storage reservoirs upon basins of these streams; but stream measurements have been secured for several years. It is probable that water storage for power purposes may be secured.

OSAGE RIVER

(Area 67)

LOCATION AND AREA

The Osage is one of the important lower tributaries of the Missouri River, flowing into it about 160 miles above its mouth. It drains a rectangular-shaped basin of 14,967 square miles, about two-thirds of which is located in southwestern Missouri and one-third in the eastern part of Kansas. The total length of the drainage basin is 250 miles. It is narrow at the upper end, gradually widens to 100 miles at the Sac River Valley, and then decreases to a narrow strip at the mouth.

TOPOGRAPHY

Its basin occupies portions of two different topographic provinces characterized by different amounts of precipitation and by soils which have different influences upon erosion and stream flow. The eastern portion is within the rough dissected region of the Ozark uplift; the central and western portions are within the level and rolling prairie region which has a more limited rainfall. Over considerable areas, most typically developed in Stone County, much of the surface has been carved into rounded flat-topped hills. This region is known as the Bald Knob section, and is quite extensively developed on the southeastern part of the Osage Basin. The elevation at the mouth of the river is about 600 feet, the head streams in the Ozark region and in the treeless hills of Kansas rising at altitudes in excess of 1,400 feet. The principal tributaries are the Little Osage, coming in from the south; the Grand, coming in from the north, and draining rolling prairie regions; and the Sac, the Pomme de Terre, and the Niangua, rising in the Ozark hills. The flow of the main Osage River, and that of many of its tributaries, is subject to a very wide range. During dry seasons the flow becomes very small for the size of the drainage basin. During some dry seasons more than half of its flow comes from the Niangua River, which is largely fed by a number of springs and which is the most eastern tributary from the south. The drainage area of this river is less than 7 per cent of the total for the basin. On account of the shape of the Osage Basin, the hilly topography of the eastern tributaries, and the small slope of the main streams, very high floods are produced by heavy rains. The flood plain of the main river varies from one-fourth to a mile in width, but those of the eastern tributaries are much narrower. Crops within the flood plain are frequently destroyed by floods.

Owing to the large drainage area of this stream and the presence of satisfactory dam and storage reservoir sites, it has good possibilities for the development of water power. The Missouri Hydroelectric Power Co. has started construction work for a power project on the

main river near Bagnell in Miller County. The dam is to be about 95 feet high, and will create a lake having a length of 96 miles, an area of 86 square miles, and generating 125,000 horsepower. At Caplinger Mills on the Sac River, the Ozark Utilities Co. has a hydroelectric power plant with a capacity of 700 horsepower. The construction of other power projects is being considered by various companies. Except during periods of excessive precipitation the reservoirs of these completed plants will be of material aid in equalizing the flow of the river. The maximum water stage recorded in a 6-year period of observation was 28.8 feet in April, 1922, with a discharge of 71,400 second-feet; the minimum stage was 0.6 feet in September, 1925, with a discharge of only 40 second-feet. There is a ratio between maximum and minimum flows of 180 to 1. According to a survey by the United States Army Engineers a stage of 45.3 feet was reached in June, 1844. The flood of December, 1895, as determined by levels to high-water mark chiseled on stone, reached a stage of 33.27 feet. At the present time small dams and power plants on the headwaters have no noticeable influence upon the extremes of flow. Twenty per cent of the area is largely within the rough mountainous province of the Ozark Dome. Eighty per cent can be classed as hilly, rolling, and level. The level areas are found in part on alluvial lands along the streams and in part on uplands, chiefly in the prairie region to the west.

GEOLOGY AND SOILS

That portion of the basin which lies within the Ozark Dome, embracing the area to the eastward and including Morgan, Benton, and Dade Counties, has soils largely from limestone and dolomite of the Cambro-Silurian Series, though there are areas of sandstone and shale. The greater portion of the middle part of the basin, however, is underlaid by shales and these extend throughout the western part of the basin. There are limited areas of sandstone and smaller areas of limestone and chert especially at the south.

The soils of the Ozark Dome region include clays, loams, silts, and gravels. Sandy soils occur on only limited areas. Many of the loams and silts contain a considerable admixture of chert and gravel, which gives them excellent subsoil drainage. The soils of the middle and western part of the basin consist of loams and silt loams, although there are areas which are clayey and others which are sandy. About 60 per cent of the area within the Ozark Dome province is broken or excessively hilly. These rough areas are in large part located on the breaks near the streams. Although there are limited areas of rough and stony soil outside of the Ozark province the total extent of such areas does not exceed 10 per cent. These areas largely consist of high divides between streams or of rocky and blufflike slopes which form part of the breaks near the streams. There are also limited areas of sand hills in the western part of the basin in Kansas.

CLIMATE

The climate of the eastern and southern portion of the basin is similar to that of the humid regions of the United States; the climate of the western portions, to that of the prairie plains. The precipi-

tation varies from an average of 45 inches a year in the Ozark Hills to about 37 inches in the extreme western part of the basin. This precipitation is characterized by a decidedly heavy rainfall during the six months from March to August, the greater proportion of which falls toward the west. The eastern part of the basin receives approximately three-fifths of the total rainfall during these six months, while the western part receives more than three-fourths of the total rainfall during these same months. This is advantageous for the production of crops. During cycles of low rainfall the western part of the basin has been subject to disastrous droughts, but the present system of dry farming minimizes their severity to a certain extent.

The snowfall varies from an average of 14 inches of unmelted snow in the extreme eastern part of the basin to 18 or 20 inches in the middle portion and 8 inches or less in the western part. The entire basin lies within the central region of frequent midsummer thunderstorms. The average number per season varies from 50 in the east to between 40 and 50 in the west. Although the basin lies north of the belt of most concentrated summer rainfall (the Southeastern States) and northeast of the region subject to irregular concentrated precipitation (the southern end of the Great Plains), the precipitation in the midsummer storms is frequently concentrated. The evaporation for the growing season varies from 25 inches in the eastern part of the basin to approximately 50 inches in the western part (where the seasonal rainfall is only about 18 inches). This high summer evaporation combined with the decreased precipitation in the west accounts for the low run-off of the western and middle tributaries of the river. The annual run-off of rainfall varies from 5.36 to 11.49 inches.

HISTORICAL DEVELOPMENT

The extreme eastern and southern portions of the basin were settled about 1820, the middle and western portions later, and the extreme western part about 1860. As a result of settlement there has been an increase in the proportion of forests on the headwaters of the southeastern tributaries, particularly Granglaize Creek and Niangua, Pomme de Terre, and Sac Rivers. At the time of first settlements there were considerable areas of oak openings on the cherty hills which marked the northern projections of the Ozark Dome province. These openings were largely the result of constant burnings by the Sac and Osage Indians, who did this to maintain the growth of blue stem, the chief prairie grass of this section. As a result of the extension of settlement during the sixties and seventies, these burnings were less frequent, and large areas of hilly land were gradually colonized by trees which pushed in from the surrounding woods. This extension of the forest area may have influenced the high flow which is maintained by the Sac River and other eastern streams, although a number of bold limestone springs, which are relatively constant in their flow, are chiefly responsible.

The prevailing type of soil on the western or prairie half of the watershed is a silt loam occupying not less than two-thirds of the upland area. It is a residual soil formed largely from shales. These soils were largely prairie, and since the first permanent settlement

in Bates County in 1830 they have been extensively cultivated, although as late as 1868 only about 10 per cent of this portion of the basin was in cultivation. At the present time a very small percentage of the prairie area and associated woodland type remains unbroken. "Corn is and always has been the most important crop of this area. It has been grown in the same field as long as a profitable yield could be obtained."[1] The crop is almost entirely fed to stock, and this reduces the depleting effect since much stable manure is now returned to the land. Secondary crops include winter wheat, flax, which is grown in certain counties, and tobacco which is the money crop in limited areas. The silt loam along the breaks and stream hills is a loose mellow soil which often puddles when thoroughly wet. Upon drying out it becomes very hard and compact. "The deeper portion which apparently contains less organic matter than the overlying material has a tendency to run together."[1] Many of these areas were originally timbered although some were in prairie, most of which is now cleared. The ease with which the silt loam on these hills can be cultivated has made it a popular and valuable soil for general farming. Since these sites are likely to gully and wash under cultivation many of them are utilized for the production of hay. This soil is often deficient in humus. It is underlain with a soft shale which lies near the surface. "When the prairie sod was first broken abundant organic matter had accumulated from the roots of the prairie grass. The soil was then loose and open, but through many years of constant cultivation the original supply of humus has been largely depleted, and as a consequence the soil particles have become more or less compact, thus indicating rapid capillarity and the loss of soil moisture at the time when it is most needed."[1]

Extensive areas of bottom land along the Osage River have been effectively reclaimed by elaborate drainage projects. Much of the land along the Osage River is occasionally damaged by flooding.

CONDITION OF LANDS OTHER THAN FOREST

The improved lands occupy about 75 per cent of the total area of the basin. The larger portion is in the western part and the smallest portion is in Laclede and Dallas Counties and along the "breaks" of the river in Benton, Morgan, Miller, and Camden Counties, Mo. But there are likewise considerable areas of rough scrub oak lands very sparsely settled. From the eastern part of Vernon and the western portions of Cedar and Dade Counties, Mo., the rough lands of the Ozark Dome region extend northeast across the basin through the southeastern corner of Henry County. It may be said that corn is the prevailing crop within the Ozark Dome region. Corn is supplemented by small grains over the western portion of the basin. Erosion comes from those cultivated lands situated on the hills which form the "breaks" along the streams. A greater portion of it comes from the lands west of the Ozark region, although there is locally considerable erosion from some of the steeper lands of the eastern and southern part of the basin. This basin lies to the south of the mantle of loess soils which

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[1] 1911 Survey of Bates County, Mo., U. S. Bureau of Soils Survey of 1908.

contribute so largely to the silty burden of the main Missouri River. While this is true, there is much erosion from the silty, loamy, and fine sandy soils on the middle and upper part of the Ozark drainage, especially from the lands which are cultivated in corn and other clean-tilled crops. This erosion can be rightly curtailed by contour plowing and by maintaining a rotation of crops in which corn occupies the land either between two grain crops or between a grass and grain crop. Even where corn land is check plowed, it is as a rule possible to "lay by" by working with the contours rather than up and down the slope. At times, the western portion of this basin has suffered extremely from drought. As a matter of fact, its early settlement was greatly retarded by a series of destructive droughts which resulted in many of the pioneer settlers abandoning their claims. Although a better system of farming and soil mulching has reduced the possibility of such serious loss during periods of low rainfall, there are still seasons of acute condition due to deficiency in precipitation. Without a doubt, in many cases, level terracing on the rolling lands would tend to alleviate this situation. Such terracing would store in the soil the excess precipitation which is now surface run-off during periods of concentrated rainfall, and at least parts of this storage water would be available for crop use during periods of drought.

CONDITION OF FOREST

The forest lands are of four kinds. Heavy stands of black and white oak occupy a large part of the Ozark Dome region. Mixed stands of scrub oak, black jack, and chinquapin oak occupy many of the thin-soiled ridges between the divides of the main streams and flats, especially over areas of rough, stony land where horizontal strata of dolomite lie near the surface. When this region was first settled these scrub oak areas, generally known as barrens, were in many cases very sparsely timbered, the trees being suppressed by periodic fires. Although these areas are capable of producing only a limited amount of saw timber, they are now being drawn upon as a source of tie material.

A third class of upland timber was the woodland. This consisted of rather open stands of post oak and black oak which extended especially along bluffs and rocky slopes well out into the prairie region of eastern Kansas. These stands have been drawn upon very heavily as sources of wood for domestic use. Though they occupy sites for the most part unsuited for the production of farm crops, their area has been considerably reduced.

A fourth class of forest lands were the swamp timbers which occupied the alluvials along the streams. Since most of the alluvials along the streams in the Ozark region are comparatively narrow, this class of timber forms only a small part of the forest growth of that section; but originally in the prairie region, where the alluvials are of considerable extent, this class was extensively developed. It has now, however, been very largely removed from this section.

The area of forest in the Ozark Hills section is probably more extensive now than at the time of settlement. This comes from accident rather than design and is a result of the protection of the woods. Most of the upland woodlands is subject to periodic burnings

which not only injure the growing trees, but also keep the stands open. Through the destruction of the humus and leaf mold this prevents the building up of the soil and the accumulation of a thick water-holding layer. The soils of the wooded portion of the Ozark region are prevailingly shallow. The general character of the soils, consisting chiefly of dolomitic clays, loams, and silty loams with considerable cohesion, is not favorable to excess erosion. The fissured nature of the underlying rocks is favorable to thorough subsoil drainage. This lessens surface run-off by promoting absorption. The stony nature of these soils and the mantle of chert which occurs over thousands of acres protects them from erosion. While all these factors are inimical to erosion, there is a comparatively heavy surface run-off of flood water due to the steepness of the slopes on the "breaks" along the streams. The accumulation of a humus blanket 2 or 3 inches thick would materially supplement the soil in storage of the excess storm water, which is now responsible for the high flood crests. If it were possible through the medium of such a surface storage to take care of precipitation which at present is not absorbed by the soil, there would be a corresponding reduction in flood crests. This is especially true on the smaller streams whose basins are largely wooded.

EFFECT OF LUMBERING

Since the woodland on this basin is entirely based on hardwood stands which are culled rather than cut clean when lumbered, the consequences of lumbering are not so disastrous as in pine stands which are cut clean. The most serious consequences of lumbering are first, the removal, with each succeeding operation of the most valuable species leaving the less valuable for perpetuation; and secondly, the lack of protection of cut-over lands from fire which, as a rule, follows lumbering operations. This burning does enormous damage to small trees by suppressing young growth, and injures the soil by destroying the humus.

EFFECT OF FIRE

Fires result in the suppression of much young growth after lumbering as well as injury to butts of larger trees. This results in permanent defects which increase by extending up the stems of trees as they become older.

In many places the fires have tended to suppress the pine, to the advantage of the hardwoods which sprout more freely.

EFFECT OF GRAZING

Grazing has seriously impaired the protective value of nearly all woods on this basin and has tended to increase flood crests.

EFFECT OF DRAINAGE

Drainage of valley lands has increased the rapidity of run-off and increased flood crests on the lower reaches of small streams.

GENERAL SUMMARY OF FOREST CONDITIONS

On the whole, the forest conditions on the basin are not satisfactory. Pine lands are being cut too close because of the fact that pine is the most valuable saw-log tree and can be profitably utilized to a very small size. Pine replacement following fires is frequently very scant. The hardwoods which constitute the larger part of the forest are deteriorating through the constant culling of the choicest species, white oak and walnut, and through the resulting extension of the less valuable black oak and black-jack oak. The soil conditions are much below a desirable standard. On account of frequent fires, humus is either scant or almost wanting. This results in a lowered absorptive capacity by the mineral soil and a reduced storage capacity for storm water.

Protective value of watershed

[Area of basin 9,579,000 acres, or 14,967 square miles]

RATINGS

Class	Area		Unit protective value	Proportionate protective value
	Acres	Per cent		
Soil:				
Alluvials	1,452,000	15.1	0.50	0.08
Clays	667,000	7.0	.50	.04
Sands	149,000	1.6	1.00	.16
Silts and loams	5,689,000	59.4	.75	.45
Stony	1,622,000	16.9	.90	.15
Total	9,579,000			.88
Topography:				
Hilly	1,916,000	20.0	.50	.10
Rolling	7,663,000	80.0	1.00	.80
Total	9,579,000			.90
Precipitation: Rainfall	9,579,000	100.0	.75	.75
Cover:				
Hardwood forest	1,511,000	15.8	.75	.12
Hardwood woodland	881,000	9.2	.50	.05
Grass	3,980,000	41.5	.85	.35
Corn	1,436,000	15.0	.50	.08
Small grain	1,771,000	18.5	.90	.17
Total	9,579,000			.77
Average				.82

FOREST COVER

Fifteen per cent of the area is woods with a protective factor of 75. The low rating of this factor is the result of excessive grazing on the farm woodland portion.

CRITICAL AREAS

There are two classes of critical areas within this basin. One consists of the steeper lands, subject to high erosion, which are now in cultivation on soils derived in part from the shales. These lands are located on the Missouri-Kansas border and also include a small area within the Ozark dome region.

The other is the steeper lands in the Ozark region still in woods. Although these lands are not subject to excessive erosion, their position immediately along the banks of the streams is favorable to most rapid run-off. This tends to synchronize the discharge of all water on a basin simultaneously into the main channel. The fullest development of forest humus is required over these areas to withhold this water. Forests on the slopes of this region thus play an extremely important rôle in equalizing stream flow and overcoming the excessive surface run-off which takes place from the unprotected parts of the basin.

RECOMMENDATIONS

The woodland on this basin, particularly that on the "breaks" along the streams and the steeper slopes on the intervening ridges, should be given a thorough protection against fire. It is probable that additional cooperative funds under the provisions of section 2 of the Clarke-McNary law are required. At the present time no radical change is necessary in methods of lumbering, since clean cutting is not yet practiced in the hardwoods and satisfactory replacement is secured where the lands are not burned. In places there is excessive pasturage, but this is largely confined to farm woods in the prairie region and on the prairie border rather than in the larger bodies of woodland as a rule connected with the farms in the Ozark.

Methods of crop practice, especially in the cultivation of corn, need to be improved. This should be secured through the cooperation of county agents with the individual landowners and the administration of State official agencies. The results will be of material benefit to both the landowner and to the local community and the influence upon stream siltage will be significant.

THE ARKANSAS RIVER (DIRECT)

(Area 68)

LOCATION

The main Arkansas River, having a length of 1,497 miles, occupies a drainage basin of 95,367 square miles. Flowing to the south of east, it empties directly into the Mississippi 700 miles above its mouth. Its watershed covers portions of five States: Arkansas, Missouri, Oklahoma, Kansas, and Colorado.

TOPOGRAPHY

The Arkansas River basin occupies four different physiographic provinces or regions:

(1) The Mississippi flood plain and costal plain region.

(2) The Ozark and Ouachita Mountain regions, discussed as the Ozark province.

(3) The prairie plains and high plains regions.

(4) The Rocky Mountain region or headwater province.

The extreme eastern end of the basin of the main Arkansas River below Little Rock lying within the nearly level Mississippi River flood plain is drained by sluggish bayous and alluvial streams. This

stretch of the river has a length of 173 miles with a fall of only 0.65 foot per mile. There are numerous oxbows marking locations of former channels and indicating that the stream channel meanders. It is this portion of the basin which is most subject to flooding as a result of high water.

That portion of the river above Little Rock and including the adjacent portion of Oklahoma, southwestern Missouri, and the extreme southeastern tip of Kansas is within the Ozark and Ouachita mountain regions. In Arkansas this portion of the river occupies a trough between the Ozark and Ouachita Mountains which wall the basin to the north and south respectively. In this portion of the river the fall is about 1.5 feet to the mile. This province extends up the main river to Arkansas City, Kans. The Arkansas River above its junction with the Canadian River " winds through a rather deep and narrow valley among the Flint Hills of the Ozarkian uplift where it is characterized by sweeping curves." The surface of the whole region lying near the river is dissected into a series of hills and hollows by the small tributary streams. The distance traversed by the river through the limestone hills is about 83 miles direct, but as traversed by the stream it is nearly twice as great. The valley between the bluffs, which are from 150 to 300 feet high, is from 1 to 5 miles wide.

The third province, consisting of the prairies and high plains occupies a broad stretch through middle Oklahoma, embraces essentially all of southern Kansas and the adjacent high plains parts of Colorado. It lies within the prairie region in the extreme east and the plains and high plains region to the west. The rise in the general levels is from an altitude of less than 800 feet at the east to 4,600 feet at Pueblo at the foot of the Rocky Mountains, a range of 3,800 feet. This portion of the basin consists of broad plains, especially to the east and northward. The Arkansas River proper, however, flows through the plains in a broad shallow valley from the point where it debouches from the mountains of Colorado after leaving the canyon of the Colorado at Canyon City, until it reaches the Flint Hills at Arkansas City, Kans., near the Oklahoma line; but the prevailingly level or rolling surface of the prairies and plains passes into a very hilly terrain in middle Kansas on the headwaters of the Neosho and Cottonwood Rivers. From Wichita, Kans., to Canyon City, Colo., a distance of 543 miles, the fall of the Arkansas River is 7.5 feet per mile.

The main Arkansas River and most of its tributaries through Kansas are skirted by a broad belt of alluvial lands, chiefly a flood plain from one-half mile to 5 miles in width. This occupies about 2 per cent of the basin. On account of the configuration of the upland surface, the limited rainfall, the treeless character of the upland, and the prevailing loess soils, which as a rule absorb most of the rains, the alluvial lands are not of high importance in connection with flood control.

The fourth or western province, the headwaters, includes the eastern slope of the Rocky Mountains south to the foothills and mesas and the inclusive valleys. This portion of the basin rises from a base level of about 5,000 feet along the plains at the edge of the foot-

hills and rapidly ascends in steep slopes to high elevations, where "at an altitude in excess of 10,000 feet the river (Arkansas) has its source in a pocket of lofty peaks in middle Colorado. There are broad valleys between the foothills but these as the streams ramify into the mountains become narrow. Through this course the river is a mountain torrent." At Canyon City the Arkansas passes out of the Rockies through the Grand Canyon of the Arkansas, largely as a clear stream, and with steadily lessening gradient flows into the plains of Colorado and Kansas.

The headwaters of the Arkansas in Colorado and including Purgatory River occupy a triangle basin about 260 miles long, Purgatory River forming the south side of the triangle and head of the Arkansas the north arm. The gradient of the river is 40 feet per mile for the lowest stretch, but the head of the Arkansas River, as well as the head of Purgatory River and of the shorter side streams, ascends very rapidly at more than 60 feet per mile. The area of this headwater province, essentially the area of the river above the mouth of Purgatory River, is about 21,000 square miles. Three thousand nine hundred square miles are classed as mountains, 4,500 as plateaus, 12,600 as plains; the mountains ranging in elevation from 8,000 to 14,000 feet, some of the peaks bearing snow fields.

GEOLOGY AND SOILS

The geological formations which underlie the basins of the Arkansas River and the soils derived therefrom vary as widely as does its surface. The extreme eastern end of the basin lying within comparatively recent formations, the Quarternary and Pleistocene, constitute the alluvials of the Mississippi bottoms and the islands of loess and the better drained areas of unconsolidated loams, clays, sands, and gravel which lie within the flood plain. It is all land which has been built up recently through contributions from the various soils on the upper portion of the basin on which erosion is now actively taking place. The loess formation is essentially limited to a few small areas, the largest being Crowleys Ridge, the western slope of which is within the basin of the Arkansas River.

A wide range of geological formations is represented in the Ozark and Ouachita physiographic regions which occupy the upland part of the basin in Arkansas, in southwestern Missouri, and in the adjacent portion of Oklahoma. The northern part of this area is formed largely of limestones and dolomites of the Ordovician period. The northwestern portion includes the Boone chert area of the lower Carboniferous or Mississippian age. The rocks in this portion of the basin are largely of limestone, with shales and sandstone to the west and north horizontally stratified. The Boston Mountains immediately to the north and the Ouachitas immediately to the south of the Arkansas River are occupied mainly by rocks of Pennsylvanian or upper Carboniferous age, consisting of some limestone and heavy deposits of sandstone and shale the strata of which are interrupted and faulted, there being monoclines from the Boston Mountains to the Arkansas River valley.

To the west of the Ozark and Ouachita Mountain province the low plains, largely of lower Carboniferous (Mississippian) age,

embrace southeastern Kansas and northeastern Oklahoma, the strata largely bedded horizontally. Pennsylvanian series of the Carboniferous age lie to the northwestward extending through middle Oklahoma northward into southeastern Kansas, the rocks prevailingly shale and sandstone, though limestone occurs in places. The Permian red sandstones, sandy shales, and clays constituting the "red beds" of the lower Carboniferous, extend over many thousands of square miles, giving the distinctive red color to the walls of the canyons, the sides of the gorges, to the local soils, imparting it to the waters of the rivers and even to the alluvial soils built up from these formations far downstream. Even where the red beds are overlaid by the more recent formations they still contribute through corrosion of banks and by erosion of slopes.

North of the Arkansas in middle Kansas and in southeastern Colorado shales of the Cretaceous age occur from which are produced an extensive series of soils chiefly silty and loamy in character.

The unconsolidated plain marls of the Tertiary sedimentary formations cover considerable areas in southwestern Kansas. Many of the sand deposits in particular border the larger streams occupying considerable areas of the high plains. Most of these deposits are unconsolidated; some are of fluvial origin, others supposed to be lacustrine; while others are of aeolean origin. They extend nearly to the upper edge of the plains in southeastern Colorado, where they commingle with the silts of the upper Cretaceous series. Below them lie the massive sandstones of the Dakota formation.

The backbone of the Rocky Mountains is formed of igneous rocks, granites, gneiss, porphyries, and gabbro.

To the north of the Arkansas River in western Kansas glacial drift occurs, but it occupies only a relatively small portion of the area of the basin.

Soils.—The soils are of three distinct types:

1. Sands and similar soils having a high storage capacity for rainfall and eroding only slightly. These soils as a rule furnish abundant springs when they rest upon impermeable or less permeable strata.
2. Silts, fine sands, and fine sandy loams which are deficient in cohesion, eroding rapidly under concentrated precipitation and contributing the largest element to the turbidity of the river.
3. Clays and related soils with much cohesion, eroding but not so readily or destructively as the silts.

Many of the soils are very stony. This is particularly so over the Ozark region throughout the Boone chert area and portions of the Ouachita Mountains. The stone is often sufficiently abundant on the surface of the soil greatly to reduce erosion, especially where it forms a mantle covering the entire surface. There are extensive areas of this kind in the Ozarks and Ouachitas and on the slopes of the Rocky Mountains, and more limited areas on the slopes of canyons and gorges. While such a mantle of stone does much to lessen erosion and to promote absorption of precipitation into soil and subsoil, it has no water-carrying capacity itself such as does humus beneath a forest in performing a similar ancillary function.

In general it may be said that over the Ozark dome silty and loamy soils prevail, but that a considerable proportion of these are protected by a mantle of chert. In the Ouachitas there are large

areas of loams and clay soils. The areas of sands in this eastern portion of the basin outside of the alluvials are limited.

In the plains and prairies the prevailing upland soils are silts and related soils subject when on a slope and when denuded to excessive erosion if precipitation is heavy. There are also extensive areas of sands bordering the larger streams.

The soils of the Rocky Mountains and its foothills are largely shallow and stony, chiefly loams and clay, though silty in places especially on the mesas. But these silty soils are often tenacious on account of a clay content, and moreover they are frequently so stony on the surface as to be protected from ordinary precipitation.

The soils of the Ozarkian province outside of the alluvials and valley lands are largely shallow or of medium depth. Over considerable areas they are stony or are covered with a mantle of chert and gravel. This cover of chert is particularly extensive on the lower part of the basin of the Neosho River and the Illinois River, but also occurs on many other parts of the basin. In many places the shales or other underlying rocks nearly come to the surface. As a rule, however, the subsoil drainage on account of the fissured character of the rock, limestones as well as shales, is good and in spite of the relatively shallow soils there is prevailingly rapid absorption of heavy rain which is promoted by the blanket of chert gravel wherever this occurs. On account of this condition, erosion of soil is not so active throughout this region as otherwise would be the case considering the frequently concentrated character of the precipitation, the steepness of the slopes, and the shallowness of the soils. The soils themselves are clays, loams, silt loams, and silts and are agricultural in character where not too shallow or stony, or where, as is often the case, the chert drift is not too thick to preclude cultivation. The rainfall throughout this province is so heavy that the soils are leached of a large part of the more soluble mineral material. In addition to the rainfall and temperature both promote the rapid oxidation and destruction of humus whether incorporated in the soil or derived from forest leaf mold.

While the soils vary widely in composition and character in the plains and prairies province, they are alike in that they have not been leached of their soluble mineral elements. This and the presence of a high proportion of lime carbonites present is the result of the limited rainfall, particularly during the winter months. The presence of the lime promotes the retention of humus in these soils and is one of the most important factors in determining their high fertility, even where derived by the decay in situ of a country rock, such as a sandstone naturally deficient in the elements of plant food. This condition grows more pronounced as the precipitation becomes less, until it reaches a point where there is too little even for the production of crops under dry-farming systems. Over the prairie or eastern portion of this province the upland soils are derived from the underlying rocks or have been but little transported, due to normal local shifting.

The soils through this high plains portion of the basin are in certain parts, especially to the northward in southern Kansas, not derived from the country rock but are of aeolian or fluvial origin, loose and unconsolidated, the surface level or in slightly rolling drifts

due to the wind action. The Arkansas River itself for several hundred miles on its south bank is flanked by a stretch of loose sand, often fixed but sometimes in transient dunes entirely unconsolidated, and this extends into Colorado. The prevailing phases are silts, loams, and clays, which are beaten into adobe by the infrequent often torrential rains which mark this country. The silts, loams, and clays of the plains follow the rivers to the foot of the mountains. The soils of the alluvials are sands, silts, and clays. Those of the eastern province have material influence upon the flowage of the river due to the constant corrosion of the banks throughout this stretch of the river. Above Arkansas City the Arkansas River occupies a broad valley with wide alluvials, mostly soils of good quality, sands, loams, and silts; a broad belt often several miles in width and extending nearly to the mouth of the canyon. The alluvial lands at the head of the river are more sandy, and are less extensive.

CLIMATE

The basin of the Arkansas River, with its wide stretch from east to west, a variation in altitude of from a few hundred feet above sea level in its eastern portion to more than 10,000 feet in its western, presents great extremes of climate, especially in precipitation, in character of precipitation, and in evaporation.

The precipitation is extremely heavy in the eastern part of the basin where at many points it is in excess of 50 inches for a year, and with only a few inches of snowfall. It becomes gradually less toward the west, reaching a minimum of less than 15 inches over limited areas of southeastern Colorado, and again rising with the ascent of the Rocky Mountains.

The heaviest rainfall, amounting to nearly 55 inches a year, is probably in Lawrence County, Ark., at an altitude of between 200 and 300 feet, although other points in the extreme eastern and southern parts of the basin show yearly averages of nearly equal amount. While this heavy annual precipitation on the lower part of the basin is evenly distributed throughout the year, decidedly more of it falls during the winter and summer months when the rainstorms from the southwest are often of a most decidedly concentrated character, particularly in the eastern, southern, and middle parts of the basin. There is a short period of low rainfall in February and a longer period in the late autumn culminating in October.

In addition to the rainstorms, chiefly from the southwest, about 40 thunderstorms usually accompanied by concentrated precipitation annually occur over the middle and eastern parts of the basin, most of them during the summer months.

The precipitation of the plains region varies from about 15 inches, of which 8 inches is unmelted snow in the eastern portion, to about 20 inches in middle Kansas, of which 18 inches is unmelted snow, and falling to 15 inches in southern Colorado. In the Rocky Mountains the precipitation rapidly rises with the altitude, amounting to from 25 to 30 inches at higher altitudes, largely in the form of snow which melts chiefly in the late spring and early summer months.

There is a difference in the character of the precipitation. That along the basin of the St. Francis River and other points in the

extreme east is decidedly of the Gulf type, heavy, and not exceptionally low during any month of the year. The precipitation of the Ozark and Ouachita regions is heaviest during the winter and late spring, and for this reason floods originating on streams in this region occur chiefly during these periods. But floods occasionally occur in the fall as shown by the flood of October 2 to 20, 1926. The precipitation in the plains region is heaviest during midsummer, often more than two-fifths of the entire annual amount falling during the four months May to August, and is relatively small during winter. There is also marked irregularity in the precipitation of this region, there being long periods of low rainfall followed by concentrated torrential downpours. As a result of this, the floods in this region are largely limited to the late spring and summer months, and local floods often take place very quickly.

The rainfall of the high plains, especially during the summer months, is of an even more irregular and concentrated character than that of the eastern portion of the basin. At Two Buttes, Baca County, Colo., with an average annual precipitation of less than 15.5 inches, 8.56 inches or more than half of the normal annual amount has fallen within a single month. At Velos 6.71 inches has fallen in April with an average annual precipitation of only 13.92 inches. For some years the total precipitation at this point has been as low as 5.38 inches.

Along the foothills and lower slopes of the Rocky Mountains there is in general this same type of rainfall, but the concentrated character of the midsummer precipitation is even more marked, often being in the form of what are called cloud-bursts, local showers of great violence and extreme suddenness. The precipitation at the upper altitudes in the mountains is largely during the winter. The melting of the accumulated winter snow in late spring and summer causes rise in the streams but no floods, the run-off merely serving to reinforce the low-water stages of the river at this point.

Evaporation.—The evaporation is low in the extreme eastern portion of the basin on account of the high humidity and the generally low-wind movement. On the plains, especially the high plains, the evaporation factor is high, especially in summer. The high temperature is often accompanied by hot, desiccating winds, the open surface evaporation being considerably in excess of the rainfall, being more than 45 inches in the plains region of Kansas. There is likewise considerable winter evaporation, mostly in the form of shrinkage from the snow after falling.

The snowfall varies from 7 inches of unmelted snow in the extreme eastern part of the basin to about 20 inches on the high plains, and in excess of 40 inches at high altitudes in the Rocky Mountains. Only upon the extreme headwater streams does the snow melt result in floods or contribute thereto, and these are local, the crests of such floods being distributed soon after entering the plains.

HISTORICAL DEVELOPMENT

The extreme eastern part of the basin of the Arkansas River was settled by the French explorers. Few of these settlements resulted in permanent agricultural development, the activities being largely limited to trading with the Indians and hunting fur. The first

extensive settlements on the basin began in the thirties, and settlement progressed steadily westward following the main drainage lines and radiating therefrom. By 1860, the beginning of the Civil War, the greater part of the basin of the Arkansas River as far as Fort Smith had been opened up. Settlements had also been made on certain parts of the Arkansas River in eastern Kansas. The Arkansas River basin of Kansas was largely opened up in the last quarter of the preceding century. That portion of the basin in Oklahoma, however, was little settled until the opening of the Indian lands for settlement in 1889, followed by the creation of the Territory of Oklahoma. There was a further inrush of settlers in 1902 and 1904, when other Indian lands were thrown open to settlement.

Settlement in the high plains country was for the purpose of grazing cattle. The range has now been largely broken up into farms, although extensive areas within the region of low rainfall in eastern Colorado, and large sections of rough land in middle Oklahoma, though largely under fence, are still handled for grazing purposes as range. The grazing of cattle in the prairie and plains section first gave to the cultivation of wheat. For various causes wheat in part gave way to Indian corn and kafir corn, while in many sections a varied system of farming has been adopted. Throughout the entire basin, however, it may be stated that drilled crops, such as wheat, are the prevailing crops, with cleaned tilled crops, such as Indian corn, kafir corn, cotton, and soy beans as secondary. There are considerable areas in alfalfa and hay but such areas on the whole are not so extensive as farther north. Large areas of rough land, the mountains and the plains, and the "breaks" still remain in use for grazing and range purposes exclusively.

Settlement has been followed by changes: (1) In the forest condition, (2) in the soil cover on the plains, (3) in the extent of erosion.

At the time of settlement large areas in the Ozark Plateau region were open prairie lands dotted with scattered trees and bushes but the ground being clothed in heavy sod, chiefly in blue-stem mixed with little bluestem. As a result of settlement such of the prairie openings within the Ozark region as have not been placed in cultivation are now occupied by woods. On the whole it seems probable that the area of woodland, at least on the Ozark drainage of the Arkansas River, is at present no smaller than at the date of settlement. As the woods have spread the bluestem has disappeared and is no longer regarded as a range or stock grass.

There has however, been a decided reduction in the forest area of the lands immediately bordering the Arkansas River in Arkansas from the mouth of the River to Fort Smith, especially on the alluvials.

There has also been some slight reduction in the wooded area of Oklahoma, but most of these woods are either on hills or located upon broken lands or upon bottoms subject to flooding, the farming lands being located chiefly on the more level and gently rolling lands. Although the forest area has extended it is doubtful if its extension has resulted in any general betterment in the protection of the surface of the soil, since the prairie grasses formed a heavy sod which gave excellent protection. On the other hand, so much of the woodland which has replaced the prairie is now repeatedly burned that

conditions are poor and there is inadequate soil protection. This applies particularly to the entire Ozark province.

The low plains and prairies of eastern Oklahoma lying within the woodland section and beyond the forested region were initially clothed in a good sod of short grasses, mostly buffalo and grama. In the middle and eastern portions of Kansas and eastern Oklahoma large areas have been cleared and put in cultivation. The result of this is far more extensive erosion from much of this land than before it was placed in cultivation. There has also been some change in the condition of the woodland, the result of excessive grazing. The more palatable browse and herbaceous plants have to a large extent been replaced by less palatable plants, particularly by prairie ragweed. which has spread enormously; but, since it is an annual, it does not give the protection to the soil during the winter and early spring which was afforded by the indigenous perennial grasses. There has been, especially in the inclosed pastures, a great increase in the amount of other unpalatable annuals, such as the narrow-leaf plantain and sneezeweed (*Helenium*). This same condition extends to the high plains, except that on the high plains a far smaller proportion of the land is tilled and a larger proportion is still in range. Range deterioration has taken place rapidly in this section, the blueweed in particular in many localities replacing the palatable and nutritious perennial grasses and, at the same time, affording far less protection to the soil from the torrential rains to which this region is subjected. The buffalo grass is one of the best soil-protective grasses, as well as one of the most nutritious. In spite of its hardiness and its ability to withstand rough treatment its sod in many places has been severely injured by tramping and by overgrazing. Other grasses, less hardy, particularly the "bunch grass," have suffered far more.

The headwater province was timbered on the mountain slopes and to some extent on the foothills, although the foothills and adjacent mesas were as a rule covered only in open woodland of cedar and pinon. Notwithstanding the fact that considerable lumbering has taken place in this region as the result of settlement, there have on the whole been less detrimental results than in the middle portion of the basin.

Forest lands, Arkansas River and main tributaries

	Square miles
Area of basin	95,367
Area of forest land	14,900
Area of woodland	2,780

The forest lands are largely within the Ozark and headwater province. In the Ozark province by far the larger portion of the woods is on farms.

CONDITION OF NONFOREST LANDS

Without doubt there has been material increase in the erosion of soil from the cultivated lands on the rolling portions of the lower part of the basin of the Arkansas River. There is also much increased erosion from the grazing land. This has very largely been due to overgrazing, to the tramping out of much of the grass by

numbers of cattle, and to the destruction of the sod through close grazing, particularly during unfavorable seasons. Close grazing likewise has greatly lessened the amount of seed which is produced and as old stools die after a normal period of life, has curtailed reestablishment of new plants.

Erosion of stream banks.—The largest amount of silty material taken from banks of the Arkansas River is a transient burden which is eroded from one hollowed bank or from a bar at one point and which farther down is deposited upon a rounded bank, or goes to build up another bar. This condition is well shown by the conditions along the banks of the river below Little Rock. "It is estimated that the eating and caving of the shore below Little Rock averages 7.64 acres every year as against 1.99 acres per mile above Little Rock." It is evident that if this corraded earth were not replaced the alluvial lands below Little Rock would rapidly shrink in area; but this is not the case, they lose at one point, but accretion takes place at another. The changes are due to the heavy silt burden of the river in this stretch. On account of this excessive burden rapid deposit takes place when the river enters the stretch of low gradient below Little Rock. Such deposit causes an adjustment of channel and current resulting in a loss at some point below. Thus change and exchange are constantly in progress in that reach of the river at which the stream for its velocity reaches the point of silt saturation. The earth which is corraded from the banks is replaced by an equal amount brought down from other sources.

CONDITION OF FOREST

The upland forests of the basin are of three types: (1) In the Ozark region they are in part pine and broadleaf and in part broadleaf; (2) the woodland which lies to the west of the heavily timbered Ozark belt, however, is entirely broadleaf. The greater portion of the plains section is treeless with the exception of the strips of timber on the alluvials and bordering the watercourses, the scrubby chinquapin oak, walnut, and the mesquite on many of the sand hills; (3) the forests at the headwaters are coniferous, chiefly of pine and spruce, the woodland also being coniferous, pinon, and cedar.

A. *Lumbering.*—On the whole, lumbering has not seriously affected the forest conditions in the Ozark region. The best pine timber has been largely cut and on many of the pine lands practically all of the pine has been taken, leaving only the scrubby oak. This is the most serious injury from the point of timber supply as well as of stream regulation. The humus on such areas has deteriorated, there being much less humus produced by the scrubby oaks than would be formed by heavy stands of pines. On the bottom lands the cutting of the hardwood timber is usually not followed by fire. As a result there is generally a good replacement and no material change in the surface conditions.

B. *Fire.*—Fire has done, and is still doing great injury to the surface condition of the upland Ozark forest in destroying humus and in suppressing young growth. This is true of both pine and broadleaf stands, especially of the pine, which sprouts feebly. The influence of the Forest Service, however, in the two national forests in the Ozark belt is decidedly beneficial, although it has not yet

reached a point at which the value of the forest is appraised as more than neutral in watershed protection. Not only are fires less frequent in the national forests but they are becoming less frequent in the adjacent privately owned woodland. Nevertheless fires still occur so frequently that the layer of humus is insufficient to add material storage.

C. *Grazing.*—Although grazing in this part directly has had material influence in extending the forests in the Ozark province, it is now having an injurious influence upon the condition of the forest. At the present time much of the woodland in this province is overgrazed, with the result that there is considerable suppression of replacement. Much erosion is induced as a result of the exposed surface. The woodland areas of eastern Oklahoma are frequently excessively grazed, being used as pastures or being attached to pastures. Wherever the slope of the surface is at all steep, erosion is excessive on account of the impairment or destruction of the vegetative cover.

In some places excessive grazing is extremely detrimental to the coniferous woodland on the headwaters through the suppression of replacement by trampling of stock. The forest lands on the headwaters are seldom grazed to excess since they are largely within national forests; some of the private lands, however, have been excessively grazed.

CRITICAL FOREST AREAS

There are five types of critical lands on the basin of the Arkansas River. Three of these are critical forest types; two are critical cover types.

Forest cover types.—In the Ozark province there are extensive areas of land largely in woods but partly cleared, large areas of which are covered with chert, and on account of this cherty surface and the porous subsoil due to the fissured limestone and shale, absorb heavy rainfall excellently. These soils, on account of this excellent absorption, are usually saturated from the winter rains at the time when the heavy late spring rains take place. Some of these areas include the barren and knobby sections and have level or gently rolling surface. Forest cover nevertheless has high value on these lands, not in promoting absorption which already freely takes place, but by means of the humus which can be developed to an additional depth of from 2 to 3 inches with a thick layer of leaf mold and litter on top. The water storage capacity of these lands can be materially increased in carrying heavy precipitation. Erosion of soil is not such a serious factor from these lands, although erosion is considerable from certain parts of the Ozark region and is high from those areas which have silty soils and which are not protected from chert largely coming from the farming lands and roads. The larger part of all lands at present in woods on the Ozark and Ouachita regions should be retained in woods, although there still remain areas which are suitable for farming purposes and which should be available for cultivation when the economic situation will permit. Forests should be reestablished on certain areas which have been cleared. Extensive areas in this belt should be incorporated in public forests, and there should be a large increase in the national-forest area on the Arkansas River.

A second class of critical forest areas embraces the lands on the steeper slopes and bluffs along streams of eastern Oklahoma and Kansas. A considerable portion of this land is still in timber, although the stands are prevailingly of the open woodland type.

A third class of critical forest areas embraces the coniferous forest lands at the headwaters, both the heavy forest and the woodland types. These lands are important in protecting the upper watersheds of streams such as the Purgatory River and other streams in the region which are subject to cloud-bursts, and which have been devastated by destructive floods such as the Pueblo flood of 1921 and the Purgatory River flood of 1904.

Cover types other than forest.—A fourth class of critical lands embraces the sparingly wooded, brush-covered, grass-covered, or even naked slopes of the "breaks," the gorges of the river and its tributaries throughout the high plains region. These are combination brush and grazing areas in large part naked. Considerable areas of rough land in northeastern Oklahoma, and in middle-eastern and along the southern edge of Kansas, particularly on the Neosho, Cottonwood and Verdigris Rivers, are in a similar class, the conditions being such that any unfavorable factor may upset the equilibrium and destroy the sod, which has a precarious existence, and by doing so make both erosion and run-off far more active. With this class may be included the considerable area, chiefly within the Ozarkian province, of naked farm land which has been abandoned.

A fifth and further class of lands which should be placed in this class are the watersheds of small streams within the treeless region upon which reservoirs are located for storage purposes. On account of the high silt burden of these streams, reservoirs silt up rapidly. In order to prolong their life it is necessary that precautionary measures be taken to reduce erosion from the surface of their basins. Even in advance of the construction of a reservoir protective measures should be inaugurated.

RECOMMENDATIONS

Forest lands.—There should be an increase in the area of public forests within the Ozark dome region upon the main Arkansas River. In Arkansas not only should the area within the existing boundaries of the national forest be consolidated but these boundaries should be extended so as to include extensive areas at present outside. Not less than 1,000,000 acres should be added to the national forest area in this State. There is likewise room in this State for an extensive series of State and other local forests, not only in the Ozarkian province but also within the lowland province. In Oklahoma, where there is a small State forest and game preserve in McCurtain County, there should be on the watershed of the Red and Arkansas Rivers not less than 1,000,000 acres in public ownership within the general Ouachita Mountain region. About 400,000 acres of this should be upon the watershed of the Arkansas River.

The results following such an extension of public ownership will be a higher earning power for the hardwood and pine lands of this region, and a resulting betterment in the humus and soil conditions throughout the region as a whole. On private forest lands prevention of fire is the acute problem throughout the entire Ozark region.

There seems to be urgent need for extending special aid to this region under the fire cooperative features of the Clarke-McNary law.

In the woodland areas of Oklahoma, southeastern Kansas, and Missouri fire is not an important problem. The forest areas are too limited in extent and wood on the whole is too valuable for fires to be allowed to run at large. The inflammability is not great and the protection received from resident owners as a rule is usually adequate. There is, however, urgent need for better control of grazing in this woodland, since it is on account of excessive grazing that the humus in these areas has been reduced or destroyed and the underbrush cover largely eliminated, with resultingly higher erosion and lowered absorption of rainfall.

In Kansas and Oklahoma, as well as in other States, there should be developed an extensive system of small public forests and parks located particularly on the steeper wooded slopes along and near the streams. These areas on the whole will be too small to be considered by the National Forest Reservation Commission. They should be in the class of local or State parks and forests. Furthermore, it is desirable that there be extensive planting of forest trees of those kinds which can be established and which will grow under the arduous conditions of the plains in middle and eastern Kansas and eastern Oklahoma. There is ample justification for planting on other portions of the basin such as for the checking of gullies on the silt soils of Crowleys Ridge and in other places where cleared lands are disastrously eroding. There should also be a great extension of windbreaks throughout this region, especially on the plains and high plains section and on rolling lands. Special provision should be made for carrying forward such a program under section 4 of the Clarke-McNary Act.

In the headwater region a considerable extension of the national-forest area is desirable, not so much on account of any influence that these forests may have upon major floods in the Mississippi River valley but as a protection against the local floods resulting from cloud-bursts, and to hold back the débris which is frequently swept into the valleys with such floods. There should be additions of 594.7 square miles to the Leadville, Pike, Cochetopa, and San Isabel National Forests, mountain lands of high protective value.

Agricultural and grass lands.—For the plains and prairie region on the basin of the Arkansas River a rigorous policy should be adopted having for its object the dual purpose of affording the largest amount of grazing compatible with maintaining the most effective protection to the surface of the country.

There is likewise opportunity for much betterment in the method of handling tilled lands. The eastern portion of Oklahoma, particularly the southeastern, has rapidly developed agriculturally and is still almost a virgin soil. In its early agricultural history, following the use of the land for grazing, small grains were the important crops. Small grain gave way in part to corn, and in Oklahoma within the past few years there have been radical changes in the agricultural system. Corn and cotton and clean tillage crops now largely prevail to the exclusion of small grain and hay. On the level lands which form the crests of the intervales little erosion follows this class of tillage. On the rolling lands, however, which extend in some places for great distances back from the streams,

erosion has been excessive. There has been very recently a general adoption of dikes of the mangum terrace type in handling clean tilled crops in this region. So far as this goes it has been beneficial but much still remains to be done along this line. Not only should these check-water systems be in universal usage where the surface is rolling but their employment should be accompanied by a more general use of cover crops together with definite systems of rotation, and with hay or nontilled forage crop of some kind alternating with a clean-tilled crop. On the steeper lands, where in spite of check-water dikes like the mangum terrace some erosion will continue to take place, level terracing may be necessary. The advantage of the level terrace will be not only to hold all of the soil but likewise to hold all of the water, a most beneficial result in a section which frequently suffers from ruinous droughts. While the general character of the precipitation is such that cover crops for the purpose of reducing erosion of soil are of less value than farther south and east, where the Gulf type of precipitation prevails, nevertheless there are heavy rainstorms during the late winter and early spring before the summer crop is established which result in enormous damage to soil and contribute large amounts of earth to the rivers.

Betterment in agricultural practice should be secured largely through the instrumentality of the county agents and through State official agencies. This phase will be largely a matter of administration through the instruction of individual landowners. It will be of prime benefit to the individual owner and to the local community, but the influence upon soil conservation through better absorption and storage of rainfall and through reducing stream siltage will be most significant. The investigation of the problems of erosion from agricultural and naked lands must be largely conducted locally, since it varies widely on different soil types and under different types of rainfall. In particular, investigation should be conducted relative to the establishment of vegetative cover on the breaks and on the hilly lands in eastern and southern Kansas which are sources of large amounts of river silt and the origin of local floods. Especially is this true on such streams as the Neosho and the Cottonwood. The upper parts of the basins of these streams are extremely hilly, the run-off of the streams from this hilly, largely naked surface being excessively flashy.

THE CANADIAN RIVER BASIN

(Area 69)

LOCATION

The Canadian River is the chief tributary of the Arkansas coming in from the south. It occupies an elongated basin of 47,552 square miles, of which 16,046 square miles is in New Mexico, 13,140 square miles is in the Panhandle of Texas, and 18,366 square miles is in Oklahoma. It flows southeast, having one main tributary, the North Canadian, which also occupies a narrow basin and empties into the South Canadian from the north at a point not far above the confluence of the South Canadian with the main Arkansas in eastern Oklahoma.

TOPOGRAPHY

The basin of the Canadian River occupies two different topographic provinces. The headwater province located in New Mexico embraces 12,500 square miles, of which area 4,600 square miles are classified as plateau, 4,000 square miles as plains, 3,900 square miles as mountains ranging in elevation from 8,000 to 12,000 feet, some of the peaks being covered with perpetual snow and having little vegetation. The North Canadian heads below the Rocky Mountains in the lower edge of the foothills and mesas. It is a typical plains stream. The remainder of the basin of the Canadian lies in the province of the Great Plains and high plains and occupies 35,180 square miles, of which 26,034 square miles are classified as level or gently rolling, 8,433 square miles as very hilly and broken, and 703 square miles as mountainous. The mountains largely consist of low ranges and isolated peaks located within the general plains province. Of the total basin, 63 per cent is classified as gently rolling, 27 per cent as very hilly and broken, and 10 per cent as mountainous. A large part of the hilly lands consists of the "breaks" which extend on both the North and South Canadians through the greater part of the Panhandle country and eastward to about the ninety-ninth meridian. Through the portion of this course in the plains, the rivers lie in canyons from 500 to 800 feet deep which in their upper part have been cut in the Dakota sandstone and flow through this canyon until the Permian red beds are reached not far west of the Texas-New Mexico line. For about 150 miles both streams flow through the red beds in valleys from 10 to 20 miles wide deeply cut into the high plains.

The escarpment and sides of these gorges, with their bad-lands structure, constitute the breaks. The flood plain, 1 to 5 miles wide on the main Canadian and very much narrower, often only consisting of gravel and river wash, on the North Canadian, occupies the bottom of the gorge 600 feet below the level of the high plains. The rivers wind over a sandy bed varying in width from half a mile to more than a mile. They are constantly shifting their channels, excavating sand in one place and depositing it in another. These slopes, the breaks, are most rugged on the south side. On the North side, especially to the east of the one hundredth meridian, there are extensive areas of sand dunes which border both the South and North Canadians, as well as a number of smaller streams. The breaks are rapidly eating back into the high plains and erosion is still vigorously in progress. The South Canadian River is perhaps more treacherous than any other stream of the plains. The river may have been dry for weeks at a time, when suddenly, without warning, a wall of water, several feet high, rushes down the channel, sweeping everything before it. For a number of days the river continues high, then gradually subsides. The source of the sudden and rapid rise is ascribed to heavy rains near the head. Such floods are by no means limited to the main stream. The smaller tributaries, as well as the North Canadian, exhibit the same phenomena.

GEOLOGY AND SOILS

The core of the Rocky Mountains, in which the South Canadian finds its source, is of Archæan rocks. To the eastward, in the foothills, lies the massive sandstone of the Dakota formation, which ex-

tends to the lavas forming many of the mesas in northeastern New Mexico. From Taloga, Okla., throughout the Panhandle of Texas and as far west as the lava formations of the mesas Tertiary beds exist, consisting of sands, clays, and conglomerates, the sand deposits in particular bordering the larger streams and occupying considerable areas of the high plains. These deposits are superficial, and most of them are unconsolidated. Below the Tertiary formations and lying east of the Cretaceous series and covering a large part of the Panhandle country of Texas and adjacent New Mexico are the Permian red beds of the also Carboniferous formation. The "Red Beds" formation extends over many thousand square miles and gives the distinctive red color to the walls of the canyon and imparts it to the waters of the rivers and even to the alluvial soils built up from the silt carried by these waters far downstream. East of the Permian red beds occupying the lower part of the basin the geological formations are the Pennsylvanian series of the Carboniferous age, shales, limestone, dolomites, gypsum, and sandstone.

The soils of the uplands are of three distinct types, although the greater portion of them lies within two types. (1) Sands and similar soils having high storage capacity for rainfall and eroded only slightly. These soils cover considerable areas in the middle portion of the basin. (2) Silts and silty loams and fine sandy loams which are deficient in cohesion and which erode rapidly under heavy rain and which contribute the largest element to the turbidity of the rivers. These soils cover extensive areas in the plains and high plains extending up to the very foothills of the mountains. (3) The clays and related soils with much cohesion are not eroding so rapidly and destructively as the silts. The areas of these soils on the whole are not as extensive as those of the other types. They are extensively developed, however, in portions of the high plains region of the Texas Panhandle. In the plains and prairie provinces while the soils vary widely in composition and character, all except the most sandy are alike in this essential element, that on account of the limited rainfall they have not been leached of their soluble mineral elements and due to this there is as a rule a high proportion of lime in the immediate subsoil. The lime promotes the retention of humus and is one of the most important factors in determining their high fertility and their dark color. The eastern soils constitute what is known as the black belt, those in the western portion the brown belt, the color differences being due to the differences in the amount of lime.

The soils of the alluvials are sands, silts, and clays; those of the North Canadian in places are little more than river wash, coarse sand, and gravel; and the alluvials along this stream are often very narrow. An important factor to be considered particularly along the South Canadian is the constant shifting of banks, which is taking place due to erosion in one place and the building up of the river banks in another.

There are 5,885 square miles, or 12.3 per cent, of sandy and porous soils upon the basin; 28,561 square miles, or 60 per cent, of silts and other easily eroded soils; 4,875 square miles, or 10.2 per cent, of clays and soils with considerable cohesion; 7,777 square miles, or 16.3 per cent, of very stony land not subject to severe erosion on this account; and 582 square miles, or 1.2 per cent, of alluvials.

CLIMATE

The greater portion of the basin of the Canadian River lies within the region of low and moderate precipitation. On the extreme eastern part the average annual rainfall does not exceed 34 inches a year. Progressing westward there is a continual decrease in the amount to the head of the North Canadian River in northeastern New Mexico, where at an altitude of about 4,000 feet on the Great Plains the minimum average rainfall on the basin occurs amounting in places to not exceeding 12 inches a year. The precipitation increases as the elevation increases from the foothills up, being in excess of 25 inches a year above 7,000 feet elevation in the mountains. the snowfall likewise increases from about 15 inches of unmelted snow on the extreme southeastern edge of the basin to more than 40 inches at high altitude at the head of the river. The character of that portion of the precipitation which falls as rain is prevailingly the same. There is a marked deficiency in winter precipitation of all kinds, especially in the plains and high-plains province. The larger part of the precipitation falls as summer rains of the most concentrated character, the precipitation at this season in many places being from three-fifths to three-fourths of the total annual rainfall. The actual benefits of the low rainfalls are reduced by the high evaporation in winter as well as summer when the plains are often swept by hot desiccating winds.

HISTORICAL DEVELOPMENT

Settlement in this entire basin was rather late, due partly to the arduous conditions and partly to the fact that the lower portion had been set aside as the Indian Territory and was not opened to settlement for farming purposes until in the last decade of the preceding century. The lands as a whole on the plains were first handled for grazing, which gave way after settlement to the cultivation of wheat, and this in turn gave way to more varied farming, including considerable dairying; so that at present practically one-half of the land which is in cultivation is in intertilled crops, such as Indian corn and kafir corn, while a considerable amount of cotton is grown at the extreme lower end of the basin. A considerable area of public lands remains, largely located on the rough breaks of the rivers and occupying other sites or soils which are inimical to profitable farming.

On the lower part of the basin the hills and slopes of the low mountains were wooded at the time of settlement with open stands of scrubby hardwoods, chiefly oaks. Farther up the forest and tree growth was restricted on the uplands to thickets of scrubby oaks which cover the sand hills. On the foothills of the mountains there were open stands of pinon and cedar, followed at higher altitudes by compact forests of pine and spruce. On the whole, however, the forest lands occupied only 13.6 per cent of the entire basin, of which only 633 square miles, or 1.3 per cent, consisted of compact forests, the remaining area, 5,880 square miles, being open woodland. The remainder of the basin, 86.4 per cent, consisted of open lands largely the boundless prairies and plains for the larger part, absolutely devoid of all woody growth, or with scattered mesquite or other trees over rough lands like the breaks, while limited areas were covered with shrubs forming stands of greater or less density but usually just scattered.

CONDITION OF LANDS OTHER THAN FOREST

There are two large classes of nonforest lands on the basin of the Canadian River. One class contains those lands which are in cultivation and which are held as parts of farms and which are located chiefly in the lower portion of the basin; the other class consists essentially of the large areas of land on the plains and breaks which are used for grazing purposes. The tilled lands are about half and half in intertilled crops and in small grain. The cultivated lands are largely the level lands, although in the southeastern portion of the basin considerable areas of rolling lands are in cultivation, both in corn and in cotton. There is extensive erosion from all of the cultivated lands which are located on slopes, the erosion rapidly increasing with the slope, and also being much greater from the lands in intertilled crops, such as corn, cotton, and sorghum, than from the lands in drilled crops. Erosion from these farm lands is at a very high rate. From slopes with a 4.2 per cent gradient where corn and cotton follow each other or some other intertilled crop it is estimated to be at the rate of 38.66 tons an acre a year from silt and silt loam soils. It is materially less from other classes of soils, particularly from the sandy soils. From grass and clover lands under the same conditions it is at the rate of less than 0.4 a ton per acre a year, or approximately one hundred times as great from corn and cotton land as from grassland. Terracing is being extensively employed on cotton and corn lands, which are rolling and hilly in the eastern and southern portions of the basin, but the use of these expedients is by no means universal.

On the whole, the largest amount of silt which is contributed to the Canadian River comes not from the agricultural lands but from the breaks along the streams which are protected by a very scant vegetative cover. While there is such excessive erosion from hilly land cultivated in intertilled crops from the plains region, as a whole erosion is slight on account of the prevailingly level surface and the excellent sod, but where the plains are rolling and hilly, especially along the breaks, the grass cover is often scanty and has in places been greatly impaired through overgrazing, particularly during dry seasons.

The open grasslands can be divided into four belts: At the foot of the mountains in the extreme west is the grama grass, in the western part of the Panhandle there is a mixture of grama and buffalo grass, in the eastern part of the Panhandle there is a wild-grass country, while in the eastern part of the basin the prevailing range grasses are the bluestem and other bunch grasses. There are, in addition, large areas in sand grass and sand sage, chiefly sand hills and the very sandy soils. Of all of these grasses the buffalo grass is the heartiest and will withstand the closest grazing during prolonged droughts with least injury.

In the western part of the Province there are extensive areas of unconsolidated upland soils. These soils as a rule would easily absorb the limited rainfall of this region. In fact, there are large areas from which there is no run-off of surplus water, all of the rainfall being absorbed, but on account of the concentrated character of the precipitation during the summer months there is often an

excessive run-off near the streams and gullies which converts arroyos and dry gorges into raging torrents and occasions enormous erosion of the soft rocks which form their beds and sides as well as of the slopes.

There is also a large amount of erosion of stream banks which lose at one point but accretion takes place at another. These changes are due to the heavy silt burden of the river, especially at certain periods. On account of this excessive burden rapid deposit takes place wherever the river enters a pool, and this deposit is compensated for by erosion at a point lower down on the stream.

CONDITION OF FOREST

The upland forests on the basin are of two distinct types: (1) The woodland, which lies in the hilly section and on the low mountains of the eastern sector of the basin and which in the shape of chaparral and brush forest extends up to the high plains following the aqueo-igneous sandy soils. These forests are entirely of hardwoods, chiefly oak, with a small amount of hickory; (2) the forests at the headwaters are coniferous, chiefly of pines and spruce, the adjacent woodland lying on the foothills being pinon and cedar.

A. *Lumbering.*—On the whole, lumbering has not seriously affected the forest conditions on this basin. Some lumbering has been done in the headwater forests, but in large part these forests are in public ownership and the cutting on the whole has been judicious. The humus as a rule has been maintained. As a result, where lumbering has been carried on and no fire has followed, there is generally a good replacement and no material permanent change in the surface condition. So little lumbering has been done in the forests of the eastern part of the basin that the situation has not been materially deleteriously affected. It has consisted more in the nature of culling the best of the hardwoods rather than clean cutting and has been largely confined to the alluvial forests, since the trees in the upland forests are as a rule of small size.

B. *Fire.*—Fire has done essentially no injury to the woodland type in the east. The headwater forests, however, have in places been badly injured. Where the forests have been destroyed by fire, replacement has not generally taken place and in the absence of ground cover there has been deleterious erosion. In some cases where cloudburst storms have resulted in local floods an enormous amount of detritus has been washed down from these naked slopes onto the valuable cultivated farms in the plains section.

C. *Grazing.*—Excessive grazing in a few places has prevented replacement and done slight injury in the mountain province. In the woodland province, however, overgrazing has done great injury. It has resulted in the extermination of the underbrush and the suppression of replacement in a large part of the upland woodland, and as a result but little humus exists in these stands and excessive erosion is taking place.

D. *Drainage.*—There has been too little drainage on this river to affect its regimen, but most of the alluvial lands which are not subject to too frequent overflow have already been drained. There is no system of levees, however, on this stream. A large amount of water is diverted from it as it enters the plains for irrigation.

CRITICAL AREAS

There are two types of critical lands on the basin of this stream: (1) Those with forest, and (2) those with cover other than forest.

Forest-cover types.—The larger part of all lands at present in woods in this basin should be regarded as critical areas and should be retained in tree growth. Furthermore, forests should be reestablished on certain areas which have been cleared or from which the timber has been cut. In the eastern or woodland section there are no large areas which are suitable for national forests, but there are extensive areas, many of them located on scenic sites as steep bluffs along rivers, in hollows, and on some of the low mountains which are admirably suited for State forests and parks or other small public holdings. A second class of forest critical areas embraces the coniferous forest lands at the headwaters, both the heavy forests and the woodland types. These lands are of particular importance in protecting the headwater streams which are subject to sudden and high floods following cloudburst rainfall.

Cover types other than forest.—An additional class of critical lands embraces the naked and sparsely covered slopes of the breaks and the gorges of the main rivers and their tributaries throughout the high plains region. These are combinations, brush, and grazing areas. The natural adjustment of vegetation hangs on a slender balance through this region, and any slight disturbance of the balance in this tension zone may result in the entire destruction of such protective cover of herbage as exists, and when destroyed nature unaided may not be able to reestablish it on account of the excessive erosion which then takes place and the unevenly distributed rainfall. These critical areas embrace, in addition to the breaks themselves, considerable stretches of grassland around the edges of the plateau. This protective fringe is necessary, since wherever the cover is weakened the heads of the gulches and gorges making up from the breaks rapidly eats back into the level terrain of the plateau.

A further class of critical areas will include the basins of small streams tributary to reservoirs planned for flood control. It will be necessary to protect such basins to minimize erosion, and thus prolong the life of storage reservoirs which otherwise would rapidly lose their storage capacity.

RECOMMENDATIONS

Forest lands.—(1) All available and suitable public lands should be added to the national forests in the headwater region and the existing national forests should be maintained in their present condition.

(2) The condition of the woodland on the lower part of the basin should be improved where as a result of excessive grazing there is no humus or ground cover and injurious erosion is taking place. The betterment of this condition must largely be a matter of research and demonstration conducted by county and other agencies. The results will insure as much if not more to the benefit of local landowners and through them to the local community as in the betterment of stream regimen and in reducing the solid burden contributed

to the streams. There is also a large area of rough land within the region of sufficient rainfall for tree growth and which is now naked, which could profitably be planted to trees. Additional appropriations under section 4 of the Clarke-McNary Act would provide for this.

(3) Provision should be made through adequate appropriation for the study of erosion control of the breaks and similar eroded areas upon which the vegetative cover is light, either naturally so or as a result of deterioration through human agencies. There should also be a study of the erosion problem in the small stream basins to be used as catchment areas.

(4) The erosion of farming lands on the lower part of the basin is essentially a problem to be handled through local demonstrators and local agencies. Landowners will largely be reached through personal interview and appeal. The use of Mangum dikes and other similar breakwaters in hillside cultivation is being employed, but these methods should be of universal application and should be developed to a high degree of effectiveness.

(5) There are a large number of areas within the woodland-forest type which are too small to be considered for national forests which should be in some form of public ownership. These areas, however, are excellently situated for State forests and parks.

CLIMATE AND STREAM FLOW

The Canadian and its tributaries have a steep slope and a rapid flow. The floods usually occur in spring and are due to the melting snow. It is only occasionally that they are due to rain, and are of short duration, rising and falling very rapidly. The great velocity of the river, however, causes these floods to be very destructive. This excess of monthly rainfall varied from 2.75 to about 6.5 inches in depth; the greatest precipitation of about 24 consecutive hours was about 4 inches. Such a downpour of rain on a basin of steep, nonabsorbent surface, with little or no storage, resulted in a sudden and very large local flood.

On the upper part of the basin but within the plains the minimum discharge of the South Canadian becomes almost nothing since the river essentially goes dry for long periods during the winter. The maximum discharge is estimated at 149,000 second-feet. The Canadian has contributed only an insignificant quota to the floods of the Mississippi River during the past 15 years.

THE CIMARRON RIVER BASIN

(Area 70)

LOCATION

This tributary of the Arkansas, joining it about 600 miles above its mouth, occupies an elongated basin having an area of 17,745 square miles and having a northwest-southeast trend. It drains a portion of northwestern Oklahoma, the extreme southwestern portion of Kansas, and small areas in the southeast portion of Colorado and in the northeastern portion of New Mexico.

TOPOGRAPHY

Its basin occupies portions of four distinct physiographic regions: (1) Its eastern part lies within the western edge of the Ozarkian or Flint Hill region; (2) for more than 150 miles it is within the low plains region; (3) its middle reaches are within the broken area known as the Gypsum Hills; (4) while from there practically to its headwaters it lies within the high plains region, barely reaching the mesas at the foothills of the Rocky Mountains.

The altitude at its mouth is about 750 feet, but its headwaters in extreme northeastern New Mexico are in the high level mesas, attaining elevations above 5,000 feet. The lower part of its basin is rolling. Much of the middle portion is hilly, and deeply dissected, the breaks extending almost to the crest of the North Canadian. The high plains to the west rise in terraces from one nearly level stretch to another, merging finally in the Black Mesa, a lava-covered plain among the vulcanic peaks of northeastern New Mexico where it has its source. The plains at its head are intersected by deep valleys, precipitous canyons, and arroyos. The arroyos may be classed as intermittent, as their normal flow is almost negligible, but during periods of melting snow in the spring they have a sustained flow and following heavy rains in the summer they become torrential. Enormous erosion takes place at this period, not so much from the level surface soil of the plains as from the sloping walls and bottom of every naked draw and canyon, the softer rocks of which are readily cut by the rapid-moving water.

Near its head the river flows through a narrow canyon cut in Dakota sandstone and follows this canyon for many miles. Below this through the red beds of the Permian the breaks, deep, narrow gorges carved into the surface of the plains, ramify on both sides for a general distance of 3 to 4 miles from the river, but the dissection is deeper and the area occupied by the breaks is wider on the south side of the river. Here the valley averages 3 miles in width and the rugged hills which border it are from 300 to 400 feet high. During this portion of its course the river is a rapid stream, having a fall of 40 feet to the mile. Between western and middle Oklahoma it flows in a broad and shallow valley carved into the level uplands of the high plains.

The drainage basin of the Cimarron is more regular in outline than that of any other tributary of the Arkansas, rarely being as much as 50 miles in width in its entire length of more than 300 miles. The tributary streams average about 30 miles in length. At irregular intervals the water sinks into the sand and passes beneath the surface for a number of miles so that in places its channel normally is dry. It is subject, however, to sudden and rapid rises, at which times the river will remain bank full for several days. Notwithstanding the limited rainfall of this region it is well supplied with bold and never-failing springs in its course through the sand hills. In a few places there are salt plains along it, with deposits from gypsum springs. For these reasons its water as well as that of many of its tributaries is often so alkaline and salty as to be undrinkable. There are 110,728 square miles of level or gently rolling lands on the basin, or 59 per cent of its area; 51,303 square miles of very hilly and broken, or 27 per cent, and 26,569 square miles, or 14 per cent, of mountainous lands.

GEOLOGY AND SOILS

The geological formations on the basin of the Cimarron River are essentially those of the Arkansas River to the north and the Canadian to the south. The eastern portion of its basin lies within the Ozark region within the lower Carboniferous (Mississippian) formation and country rock, generally of shales. The middle portion is within the upper Carboniferous (Pennsylvanian). The formations are prevailingly limestone, sandstone, dolomites, and gypsum, the sandstones and shales being prevailingly red in color. Throughout the region of the panhandle and high plains the Permian red beds, sandstones, shales, and sand shales, mostly red, interbedded with unconsolidated clays are the chief underlying geological formations. The "Red Beds" give the waters of the river their characteristic color. On account of the scanty rainfall the soils are unleached, and for this reason the fluvial deposits of silt, even at the mouth of the river, partake of the same red color as the sandstone.

Capping the Permian red beds there are sand hills of Tertiary age which skirt the river on its north bank for many miles, and there are other areas of unconsolidated formations of either Aeolian or Lacustrine origin, or both. Near the head of the basin cretaceous sandstone of the Dakota formation forms the underlying rock covered in places as in the Black Mesa by lava flow, angular fragments of which also strew some of the mesas.

The rainfall in the eastern portion of the basin is sufficiently heavy for a considerable surface run-off, with the result that the general level of the plains to a considerable distance back from the drainage lines is being carved into a rolling surface which becomes more hilly and precipitous near the stream. The shale is much fissured. There is, as a rule, good subsoil drainage, and erosion and undermining of the shale itself is not common.

In the middle portion of the basin the streams in large part flow in gorges. The rocks are prevailingly indurated, of hard texture, and on account of the lessened rainfall are not seriously affected by erosive action. There is also, as a rule, a prevailingly good cover of sod except where it has been impaired or destroyed through excessive grazing or by cultivation.

In the high plains and the Panhandle country the sandstones and sandy shales as well as the indurated clay formations which are interbedded are all subject to erosion which is taking place at an excessive rate along the streams. As a result, the soil mantle on knolls along the breaks is frequently only a few inches deep. Frequent excessive precipitation resulting in torrential stages in the streams for brief periods causes continuous deepening of gullies and arroyos and the undermining of soft rocks along stream banks.

In the middle part of the basin there are considerable areas of land unfit for cultivation, either on account of alkali, salt or shallow soil, or rough or steep surface.

In the high-plains region there exists one large area of level land, located between this river and the North Canadian. The prevailing soils are sandy and silty loams formed largely from unconsolidated deposits of Tertiary and Quaternary age, but in places, especially on

slopes, from the weathering in situ of the country rock. In the sandy and fine sandy members wind action has played a part in the formation, although much of the sandy material was doubtless originally deposited by water. The surface is level, gently undulating, or is sometimes marked by small hills and dunes in the sandy phases. These sands cover about 5 per cent of the area of the middle part of the basin, lying principally on the north side of the river. They are covered with coarse grasses, particularly broom grass, some beard grass, with sagebrush and bear grass (*Yucca*) and thickets of shin oak (*Quercus undulata*), which is scarcely more than a shrub. The mobile dunes are often bare of vegetation. These sandy soils absorb all, even the torrential rails, and from them there is no surface run-off. They are the source of innumberable, bold, sweetwater springs.

The silty, loamy, and clayey soils which prevailingly cover the level portions of the plains region were covered with an abundance of native grasses, especially the buffalo, mesquite, or grama grasses, all of which make excellent pasturage. Practically all of this class of land is tillable and with the development of dry-farming practice it is rapidly being placed in cultivation wherever the rainfall is sufficient or water for irrigation can be secured.

Occasionally, especially on the most close-textured soils on the high-plateau areas, there are numerous small lake beds, some containing more than 100 acres. These act as catchment basins for water not absorbed direct by the soil. They are sometimes dry for several years. Very few streams extend over the surface of the face of the plateau, and these consist of dry-shale draws which are the headwaters of some of the creeks and rivers. Heavy winds, rapidly changing weather in the spring at the time when buds may be partly open, periods of dry, hot, and desiccating winds militate against general orcharding throughout this entire region. Windbreaks are essential to protect orchards of any kind, especially in the spring.

There are large areas of rough, broken land in the breaks of the Cimarron River. This includes stone escarpments around the edge of the high plains or other rough areas along the streams wherever erosion has deeply carved the surface. These escarpments often occur as almost perpendicular bluffs, sometimes as a series of steps, some of them through beds of the red Permian sandstone, but lower down outcrops of gypsum and dolomite are abundant. The soil on these sections is relatively thin and the constant erosion prevents its accumulation. On the more gently sloping walls and narrow valley bottoms good prairie grasses abound but on the rougher portions only a scanty growth of coarse tussocky grass occurs. Occasionally a few red cedars and mesquite trees are found, sometimes small thickets of scrub oak and bushes. On the stream bottoms bands of timber, principally poplar and hackberry, fringe the streams. On this basin there are 900 square miles, or 5 per cent of its area, in sands or sandy soils; 13,245 square miles, or 75 per cent, in silts or other easily eroded; 2,500 square miles, or 14 per cent, are clays and soils with cohesion; 834 square miles, or 4 per cent, are very stony lands, not subject to severe erosion on account of the stony surface; while 200 square miles, or 2 per cent, are alluvials.

CLIMATE

The climate of the entire basin is continental—that of interior plains and high plains from 1,000 to 5,000 feet above sea level. In the eastern sector the average annual precipitation is from 30 to 35 inches; in the western the precipitation in places is as little as 12 inches a year where desert conditions prevail. The snowfall varies from about 10 inches of unmelted snow in the east to 20 inches in certain portions of the high plains. The type of precipitation is the same throughout the basin, very light during the winter, the greater portion falling during the summer in irregularly distributed but torrential showers. This is a character of precipitation which does not permit a very high proportion to be absorbed on sloping sites and which tends to result in high erosion.

HISTORICAL DEVELOPMENT

Practically the entire settlement of the basin of the Cimarron has taken place within a generation. The opening of Indian reservation lands to settlement, the creation of Oklahoma as a State, and the development of the Panhandle country under dry-farming methods are events of a few decades. Within this period the greater part of the prairie sod has been broken and the land has passed through three distinct forms of agricultural use—first, the open unfenced cattle range, followed by the extensive cultivation of wheat, which, in turn, has largely given place to the raising of sorghums and other intertilled crops.

CONDITION OF NONFOREST LANDS

The nonforest lands are of two classes, those which are tilled and the grazing lands, the grazing lands largely prairie and plain sod. The cultivated lands largely occupy the more level areas; much of the grazing land, however, is within hilly sections or upon the breaks along the streams. Due to excessive grazing the sod on much of this land has deteriorated and under the torrential rains accelerated erosion is taking place, especially from the Permian soils known as the "Red Beds."

FOREST LANDS

There is no forest land on the basin other than limited stretches along the alluvials on the lower reaches of the river. On the upper reaches the trees along the streams are limited to a fringe immediately along the banks. There are, however, limited areas of parklike oak woods on the hills of the lower portion of the basin. This woodland area amounts to 251 square miles, or 1.3 per cent of the area of the basin. These woods are essentially restricted to hilly and broken lands. They are largely devoid of undergrowth, and little replacement is taking place, due to their prevalent use for cattle lots and as woodland range. Fire is not a problem.

CRITICAL AREAS

The breaks along the upper portion of the river and its immediate tributaries and the hills skirting its lower reaches are critical areas. Although there are no true critical forest lands, the cover in the upland woodland type should be maintained. Essentially all of the upland woodland is on slopes, and the use of these lands as pasture has resulted in the destruction of the ground cover, the loss of humus, and has greatly increased erosion.

RECOMMENDATIONS

(1) The woodland areas should be so maintained and through demonstration the owners should be instructed in proper management methods as to secure replacement of the stands and maintenance of the humus cover.

(2) A large portion of these critical woodlands where the slopes are so steep that the permanence of the soil is in jeopardy through private ownership should be acquired for State or county forest parks.

(3) Better range management of lands is needed.

(4) A thorough investigation of the grazing problem of the park lands is needed to ascertain the methods of replacement of a cover over those areas which are eroding.

ADDITIONAL DATA ON FOREST COVER AND FLOOD CONTROL

Floods.—The most disastrous flood on the upper part of the dry Cimarron was the Folsom flood of August, 1908, costing many lives and almost totally destroying the town. This flood clearly indicates the treacherous and dangerous character of this river. It was produced by a rainfall of practically 4 inches which occurred immediately preceding the flood. The precipitation for August is not infrequently in excess of 4 inches in this portion of the basin though not so concentrated. For August, 1907, it was 5.53 inches. For August, 1910, it was 5.38. Although the average rainfall for the year at Folsom is only about 19 inches, three-quarters of it normally falls during five summer months.

Reservoirs for flood control.—The State of New Mexico, under plans prepared by Hugo March, jr., and State Engineer George M. Neel in 1925, has located sites for two reservoirs on the head of the dry Cimarron above Folsom and one below Folsom. Of those above Folsom, one, the Morrow, calls for a dam 120 feet high, to impound 21,506 acre-feet of water, and having a drainage area of 45 square miles. The other is to have a dam 40 feet high, impounding 11,716 acre-feet of water. The site below Folsom, known as the Baker Reservoir site, is considered to be admirably situated for flood control and for irrigation. It is located just above valley. The dam would have a height of 80 feet and would impound 20,000 acre-feet of water.

The Oklahoma State Commission of Drainage, Irrigation and Reclamation has developed plans for 18 conservancy reservoirs on the

basin of the Cimarron for flood control. These reservoirs would begin near the New Mexico line and would extend practically to the mouth of the river. They would have a total storage capacity of 1,746,800 acre-feet, or when supplemented by those proposed in New Mexico, a total of 1,800,930 acre-feet. This storage capacity would take care of a general rain of nearly 3 inches over basins of the streams upon which the reservoirs are located. The town of Okmulgee secures its domestic water supply from a reservoir located on a tributary stream near the mouth of the river. The life and ultimate value of these reservoirs will depend largely upon the control of erosion of soil, preventing the loss of storage capacity through sedimentation. This control must largely come through maintaining soil cover and reducing corrosion of banks.

Cover.—There is no real upland forest upon the basin of the Cimarron River. Its lower portions are within the woodland belt which lies immediately to the east of the prairies and intermingles with the prairies. The woodland area of this portion of the basin amounts to 143,000 acres. It consists of scattered groves of small trees in open stands, the trees being chiefly post oak, blackjack oak, and black hickory, while occasionally there is a clump of cedars, or, farther west, there are areas of cedar glades or barrens. The woodland fortunately is largely confined to the rolling and hilly lands where it functions most efficiently. In many places on the soils derived from shales near the streams there are sometimes found extensive thickets of red haws. In the middle portion of the basin on favored spots even woodland formed of trees of medium size occurs on the uplands. Thickets of scrub oak occupy a large portion of the sand soils skirting the river on its north side. There are trees, especially cedar, sometimes thickets of scrub oak, as well as of other classes of brush on the rougher hills and breaks which are well developed on the north side and which extend nearly to the New Mexico State line. It is exceptional, however, for humus to develop even in the scrub-oak thickets. The strong winds which characterize winter and spring on this part of the basin blow away most of the leaves and prevent their accumulation.

On the headwaters lying within the State of New Mexico the pinon types of the Rocky Mountains occurs over local areas. The tops of the highest mesas, especially on north sides from the head of the river down to Long Canyon, are covered with pinon trees and a sparse stand of grass. The pinon grows usually in rocky places, especially on sandstones and igneous rock, seldom on soil derived from marine shale. In canyons on the upper basin, as in particular Oak Canyon, scrub oak grows in abundance, concealing the underlying rocks and affording great protection to the scant soil against erosion. Invariably the slopes of the mesas above an altitude of 7,000 feet are also covered with the dense oak thickets, which not only hold the soil but even prevent the rocks from being washed down into the valleys. Along the watercourses in the upper parts of the basin only cottonwoods and a few willows grow. On the lower reaches these trees are supplemented by hackberry, elm, and sycamore.

WHITE RIVER BASIN

(Area 71)

LOCATION AND AREA

The White River, 690 miles long and draining an area of 27,678 square miles, is the largest lower tributary of the Arkansas River and in point of contribution of flood water is more important than all of the other portions of the Arkansas drainage. Rising in extreme northwestern Arkansas, it flows north into Missouri and then turns southeast and flows through northeastern Arkansas, draining the entire northern portion of that State and the greater part of southern Missouri. Its principal tributaries in its upper reaches are Kings and Buffalo Rivers, which drain the south side of the loop, and James River and Beaver and Bryant Creeks which come in from the north. The eastern portion of the basin is drained by Cash River, together with Black River, with its western tributaries, Strawberry, Spring, and Current Rivers; while the Little Red River and Cypress and Lagrue Bayous drain the lower part of the basin on the south and west sides.

TOPOGRAPHY

The drainage basin is pear-shaped with the broad end resting across the southern part of the State of Missouri, the main axis being northwest and southeast about 380 miles long and 240 miles across in northeast and southwest direction. The shape of the drainage basin and the steep slopes of the valley sites are conducive to high floods, the tributaries being flashy streams and the waters of several of the converging tributaries emptying simultaneously. The basin of the river lies in two distinct topographic provinces. The greater part of the basin to the north and west above Newport lies within the Ozark uplift, a hilly and broken region, in places mountainous, and with only limited areas of level and rolling surface. The southern and southeastern part of the basin, beginning in the eastern part of Butler County, Mo., and extending southward, parallel with and including the valley of Black River, to Newport, and from Newport southwest, closely paralleling the line of the Missouri Pacific Railroad, is within the general alluvial region known as the Mississippi Valley. This region is largely level, gently rolling, or in places dotted with remnants of former bluffs or old terraces which rise above the general level of the surface. This region is at times, except for these scattered eminences, subject to flooding.

It is only over a comparatively small portion of the basin that the ridges are sufficiently high above the drainage lines and their crests sufficiently well defined to be called mountains. Of the total area of the basin, 8,837 square miles, or 32 per cent, are characterized as having level or gently rolling surface; 11,322 square miles, or 41 per cent, have a very hilly and extremely broken surface, while 7,455 square miles, or 27 per cent, are of a character which can be called mountainous.

While that portion of the Ozark Plateau which is deeply dissected and broken into rough hills is prevailingly characteristic of the extreme northeastern part of the White River Basin, including nearly all of the upper drainage of the Current and Black Rivers, there is to the west of this rough belt an extensive area designated under various local names to suit the character of surface and forest growth but generally known along its southern edge where the largest area occurs as the barrens. The barrens and associated areas occupy a broad belt beginning on the headwaters of the north fork of the White River and the upper tributaries of Bryant Creek and extend in a general southeasterly direction.

This region has two very definite and pronounced characters of surface and soil. In one case the surface is gently undulating. The stream valleys are shallow. The small streams lie in mere sags. A great many of the smaller drainage lines end in broad, shallow depressions with no surface outlet. The usual drainage maps of the region show a large part of this area blank as though no drainage lines existed. They do exist but are not pronounced, and many of them end in basins without surface outlets. These saucer-shaped basins may range in size from a few rods to half a mile in diameter. Another type consists of knolls and low ridges which are extremely stony. They contain large fragments of chert. These areas are not rough in the usual Ozarkian sense but are far rougher than the basins just described. The valleys are rarely more than 125 feet deep, and the slopes are often not too steep for cultivation in cases where the soil is deep enough to allow it and not too stony. These areas are frequently known as glades. Except toward the south in Arkansas this phase does not occur in large areas but occupies a great number of small bodies. All over the areas where these soils occur the limestone beds are frequently exposed. It is sometimes characterized under the name of "balds." It is a conspicuous feature in the White River Basin and to a somewhat lesser extent in that of the adjacent parts of the Osage and Gasconade.

The soils of the glades are prevailingly shallow. They sometimes lie upon a bed of limestone or dolomite in a layer from 6 to 12 inches thick and practically stone free. In other places there may be a layer of stone-free soil on the surface and beneath this a foot or more of soil containing from 20 to 80 per cent of sharp, cherty gravel or loose stone. On account of their shallowness and the prevailingly thorough subsoil drainage of the fissured bedrock, there is a generally thorough drainage. The tree growth which they support is consequently small. On the barrens proper, where the limestone does not run too close to the surface, the predominant tree is red oak; with it is associated some black oak, post oak, white oak, and hickory. The timber growth is vigorous though small. The trees are often not yet mature; the average diameter is about a foot. Undoubtedly much of the stocking of some of these areas has taken place since the settlement of the country. On the Mountain Home barrens in Baxter County, Ark., and on similar areas where the sags are a characteristic feature with soils a foot deep and either cherty or chert free, the most abundant tree is post oak, being the typical tree on the shallow soil glades and the gray soil with moderate to poor drainage. Along with the post oak and more or less alternating with it on the

drier sites is blackjack oak. These two species largely make up the forest on extensive areas. As the soils become thinner and the bedrock lies nearer the surface, the forest passes into the cedar glades, which are largely occupied by chinquapin oak and red cedar. The soil of the cedar glades is largely organic matter, and the entire forest of this type is often wiped out by a single fire.

The White River has a minimum and maximum discharge at its mouth of 4,500 cubic feet and 402,000 cubic feet per second, respectively. In high-water seasons Forsythe, Mo., 505 miles from the Mississippi River, was the head of steamboat navigation. At the present time channel maintenance only goes to Batesville, Ark., 301 miles above the mouth. So constant is the low-water flow of the White River that "vessels drawing 2 feet of water could have plied from Newport to Clarendon, Ark., at any time since 1880, except during a period of 37 days, although it is not possible always to cross the shoals at the mouth of the river." A total of $336,000 had been expended in the improvement of the White River by the United States up to June 30, 1926. The amount of traffic on the White River in 1925 amounted to 270,000 short tons, but the traffic on Current and St. Francis Rivers amounted to 177,000 in addition.

At Beaver, Carroll County, Ark., where the White River drains a basin of 1,270 square miles, the maximum water stage recorded in the period of measurements from 1923 to 1926 was 18.35 feet in May, 1924, with a discharge of 23,500 second-feet; the minimum stage was 2.15 feet in August, 1923, with a minimum discharge of 33 second-feet. This shows wide fluctuations in the flow of the river near its headwaters. At this point the run-off for the period given amounted to 11.66 inches a year out of a rainfall of more than 40 inches a year.

GEOLOGY

The greater portion of the White River Basin is underlaid by limestones, dolomites, and associated rocks of the Ordovician age. The limestones and dolomites are in places highly fissured, resulting in excellent subsoil drainage and high water storage capacity, which results in a large number of extremely bold springs on many of the watersheds within the basin, and very great regularity of stream flow, the minimum flow of the river being exceptionally high on account of the geological structure.

SOILS

The upland soils are prevailingly silty or have a large silty component, silty loams and silty clay loams, although clay silts and fine sandy silts prevail over more limited areas. A characteristic of the surface of a large part of the basin is the mantle of chert gravel which over extensive areas is so deep or the gravel may become so large as to preclude the possibility of profitable farming. While this mantle of gravel limits the use of the land for agricultural purposes it also tends greatly to lessen erosion of soil. In many instances where the blanket of gravel is not thick enough to prevent the use of the land for farming, although it lessens its value for this purpose, it nevertheless performs a high function in reducing erosion

where the gradient of the sites is at all steep. The silty soils on this basin, where unprotected either by the gravel coating or by vegatative cover, erode freely. Some of them, such as the loessal silts of Crowley's ridge, erode destructively. The clay soils having greater cohesion are not so subject to such destructive erosion, although erosion takes place it is slow. The sandy soils, as elsewhere, absorb rainfall freely and with little run-off and consequently erode slightly. Two thousand and eighty-five square miles, or 7 per cent of the soils of this basin, are classified as porous sands and sandy loams; 9,114 square miles, or 33 per cent of the area of the basin, are classified as silts and other silty easily eroded soils; 2,400 square miles, or 9 per cent of the basin, are classified as clays and soils with cohesion, eroding less freely; 13,254 square miles, or 48 per cent, are classified as very stony land on the surface, the chert mantle being so thick as greatly to minimize erosion; 761 square miles, or 3 per cent, consists of alluvials, largely in cultivation. There are considerable areas of very shallow soil within the barrens and glades, more specifically referred to under the heading "Topography."

CLIMATE

Over the greater part of the White River Basin the average annual precipitation is about 45 inches and the amount of unmelted snowfall about 7 inches. The heaviest precipitation, amounting to nearly 55 inches a year, is at an altitude between 200 and 300 feet, although other points in the extreme eastern and southern parts of the basin show yearly averages of nearly equal amount. The rainfall is of two distinct types; that in the eastern and southern portions being of the Gulf type, fairly evenly distributed throughout the year; but decidedly more of it falls during the winter and summer months when the rainstorms from the southwest are more concentrated. There is a short period of low rainfall in February and a longer period in the late autumn, culminating in October.

The annual snowfall is light at the southern end of the basin, averaging about 7 inches of unmelted snow a year, and in the northern portions about 12 inches.

The precipitation in the western portion of the basin is of the plains type, heaviest during spring and midsummer, often more than two-fifths of the entire annual amount falling during this period, and somewhat lighter during the winter. The result of these types of precipitation is that while general floods on the main White River are essentially limited to the spring and summer, rarely occurring in the fall, floods on the St. Francis River, and smaller streams in the extreme eastern part of the basin may occur in winter as well as in spring and summer.

HISTORICAL DEVELOPMENT

The oldest settlements in the extreme eastern part of the basin were made approximately 200 years ago under old Spanish grants. Very little land was cleared at that time. The mining prospectors were followed in the eighteenth century by French trappers and fur traders who established permanent settlements and gave names to many streams and other topographical features. The more perma-

nent settlements were made by the pioneers seeking homes. The red limestone soils in the eastern part of the region began to attract attention about the beginning of the third decade in the past century. Soon afterwards the hill people from the base of southern Appalachian region, and from Tennessee in particular, following the streams, had pushed their settlements to the central part of the White River Basin. The greater part of the White River Basin was up to the middle of that century a region of open woods, large areas being almost treeless. Agricultural development in the region as a whole reached its climax in the early eighties, since which time it has been on the decline. The alluvial land drainage attracted many from hillside farms; the opening of the Oklahoma lands attracted many; and the lure of the irrigated basins in the extreme West called still others from the hillside farms. Thousands of acres were thus abandoned. Mineral speculation, particularly during the last decade of the past century, led to the purchase of many of these farms by rather large owners. At present there are large acreages held for mineral purposes, not only within the known mineral regions of southwestern Missouri and headwaters of the basin but likewise at many other places where speculation rather than development was the objective of promoters.

In such a region of prevailingly low and medium grade soils it is not surprising that every effort was made by the home builders to maintain their communities. A signal effort along this line was the development of orcharding. Practically the entire middle and upper portion of the basin has at one time or another been considered as suitable for fruit growing. Undoubtedly considerable areas are well adapted to the production of the larger fruits, but climatic conditions over a considerable part of the eastern and middle basin have prevented fruit raising upon a permanent and profitable basis. Thousands of acres planted to apples have been practically abandoned, due to crop failure succeeding crop failure over long periods, caused by frequent killing or injury by spring frosts. This does not mean that there are not certain areas which are suited to fruit culture, but it has been found from experience that certain other areas are not so suited. A further limiting cause is the shallowness of the soil on extensive areas of level lands in the glades and barrens where the surface is smooth and free from the blanket of gravel. There are, however, limited areas of uplands of excellent quality and larger areas of middle quality. The alluvial lands, on the whole, are not of great extent.

The population of the basin, as a whole, is now considerably less than at the time of its optimum development. There are no large cities upon it, and the water power which is now being developed will inure but little to local benefit, since under electric transmission it will be sold in the more profitable field of the cities. Even the mining industry is now far less important in some counties than formerly. Extensive areas, largely in small farms, were placed in cultivation during the 1890's and the following decade, at which period the climax was reached of farm development on this basin. Since then not only has a far smaller area of land been cleared, but in many communities so many farms have been abandoned on account of the changes in living standards that the area now farmed is smaller than it was a quarter of a century ago.

When settled, there were extensive areas of open lands on the northern and western portions of the basin. These lands were of two different types, one prairies or oak openings, the ground cover of both being a dense sod of bluestem and other coarse grasses. The other class, known as barrens or knobby areas, consisted of lands having thin soil, in some places quite stony or covered with bowlders dotted with small scattered trees or covered with bushes but not stocked to prairie grass. As a result of settlement such of the prairie openings as have not been placed in cultivation are now occupied by woods, while both the barrens and the knobs are almost solidly in forests of small trees. It seems probable that the area of woodland, at least on the upper portion of the White River, is at present no smaller than at the date of settlement. As the woods have spread the bluestem has disappeared and is no longer regarded as a range or stock grass. There has, however, been a decided reduction in the forest area of the lands immediately bordering the lower reaches of the White and St. Francis and other tributaries within the Mississippi Valley zone. In Ripley County, Mo., typical of much of the White River Basin, the population is only 20 per square mile.

CONDITION OF LANDS OTHER THAN FOREST

The nonforested lands on the White River Basin at the present time consist entirely of lands which are either being farmed or which have been cleared for farming purposes. It is probable that of the lands cleared for farming not less than 10 per cent are now no longer farmed, and have either been abandoned or have been acquired by lumber companies or others in connection with the purchase of the timberlands on the farms. The uplands which have been cleared and placed in cultivation very largely consist of the more level areas, and those which are freest from stone and gravel. On account of the general deficiency in humus of the virgin upland soils of this region and the consequent low productivity while freshly cleared, the rougher and steeper lands in the Ozark region as a whole have not offered the same inducement for clearing as has been the case with steep lands in the Appalachian Mountains. Consequently there has been a far smaller proportion of rough lands in cultivation.

Thirty-two per cent of the area is nonforest, largely in cultivated lands or lands which have been cultivated and are now abandoned. There are at present no natural untimbered lands on the basin. The alluvial lands which are in cultivation are on the whole in good condition. On the lower part of the basin there is some erosion of banks, but on the whole this is slight. Large numbers of drainage ditches have been constructed, particularly on the lower part of the basin of the Black and Current Rivers, and in some sections the silting of these ditches is serious while in others the cutting of banks is a problem, but on the whole the condition of the alluvial lands, except for occasional flooding, is good. The cultivated upland soils with level and rolling surface generally are in fair condition so far as erosion is concerned. Many of these lands, however, are very deficient in humus and consequently are deficient in absorptive capacity. The more rolling and hilly cultivated lands, however, where the surface is unprotected by gravel mantle are subject to con-

siderable erosion, the amount varying on different types of soil and under different degrees of slope.

The White River, as its name indicates, was normally a clear stream in contrast with the Arkansas into which it empties. At present its silt burden amounts to about 2,851,000 tons a year, or approximately 103 tons per square mile of drainage area, 11 per cent of the total silt burden of the Arkansas River as a whole, by far too large an amount considering the soil of this drainage basin.

CONDITION OF FOREST

There are 18,700 square miles of forest lands in the basin, or 68 per cent of its total area. Of the wooded area, 333 square miles lie within national-forest boundaries, within which, in addition to the public land, 43,789 acres have been or are being acquired as additions; 41 square miles is within State forests or State parks. The proportion of forested lands is probably fully as large at present as at the beginning of settlement. There are considerable areas on the flat-topped ridges which were originally entirely open prairies or were dotted with bunches of brush or groups of trees, but the surface was essentially covered with tall bluestem prairie grass. These openings have passed away as a consequence of settlement, the surrounding woods gradually encroaching until they have now practically taken full possession except where the land has been cleared for farming. Although the area in woods has not decreased the periodic fires have prevented the accumulation of a normal humus not only beneath the newly established forest but also over the greater portion of the forest lands in the basin. For this reason the forest soil is not at its highest point of effectiveness for the storage of storm water. Tests seem to show that the forest lands in the Ozarkian province might with better humus withhold a total of 44 billion cubic feet of water, or at the rate of 158,000 cubic feet for a period of 3 days 5½ hours, which, theoretically, would have been the equivalent in the reduction of 7.8 feet in the 60.5-foot flood stage of the Mississippi River at Arkansas City for this period.

There are three broad types of forests within the basin. The pine type, the uplands hardwoods, and swamp hardwoods. Of these the upland hardwood occupies by far the largest area, approximately 78 per cent, the pine about 17 per cent, and lowland hardwoods at the present time not to exceed 5 per cent.

The prevailing hardwood type over the entire basin is mixed hardwoods with oaks predominating, this mixture being associated with yellow pine of large size and fine quality on certain sites, particularly in the eastern and southwestern parts of the basin. Over large thin-soiled areas scrub oak, associated with small specimens of northern red oak, forms the characteristic growth; while on cherty red clay lands blackjack oak predominates over large areas. These wooded lands as a rule are periodically burned with the result that there are few areas where the humus has accumulated to a normal depth. In consequence some erosion takes place over much of the woodland and these soils are deficient in absorptive and storage capacity for storm water. Much of the woodland is in small bodies attached to farms, but in sections there are large areas of wild lands belonging to lum-

ber or mining companies or held for speculative purposes. Most of the best pine timber has been cut from these lands within the pine type, the cutting in many places being so close as to have removed most of the trees which would have been available for seed trees, with the result that the proportion of pine has been greatly reduced and the earning value of the lands correspondingly depreciated. The pinelands all contained merchantable timber and the pine was one of the first trees to be cut and sold. On account of its lightness, it could be floated down such streams as the Currant and Black Rivers, and large quantities were rafted out in this manner from the pinelands in the northeastern part of the basin.

There are three different conditions represented by the hardwoods. Along the eastern part of the basin and on the alluvial lands were excellent hardwood forests of large old timber, the trees sound and of fine quality. Much of this timber has been cut. The white oak in particular has been severely cut, particularly for staves, the upland white oak of this region making a spirits' barrel stave of exceptionally fine quality for export. The making of staves for many decades has been an important industry over many parts of the basin. A portion of the remaining upland hardwood timber consisted of stands largely of black oak, though in places with a high admixture of white oak of only medium quality, in part fire damaged, and with the concomitant deterioration caused by fungi and insects which follow fire damage. A large part of this timber is of medium and low grade and is for this reason not yet suitable for marketing. Considerable bodies of this class remain unlumbered or culled, but only the choicest trees remain in the northern and western parts of the basin. Some of this timber is of comparatively small size, is young and thrifty, though often fire scarred.

There are large areas of shallow soil where either all or much of the timber is small, where it will never be large on account of the physical limitations. These sites vary. Some will produce timber of sufficient size for small saw logs, other sites only of sufficient size for railroad ties, while the poorer sites will produce only firewood.

A. *Lumber.*—On account of the value of the pine timber and the ease with which it can be handled and its general good quality, pine has been cut more closely than any other species. The pine stands in the northeastern part of the basin have been as a rule so closely cut that in some cases there is a deficiency of seed trees and a great lack of those aged classes which would make a profitable cutting within the next 50 years. In a few places, especially along the eastern border, where there has been general lumbering of hardwoods, the hardwood stands have been very closely cut. This has resulted in the reduction in the amount of some of the more valuable species like walnut and white oak, while the productive capacity of the forest has been impaired seriously by such close cutting.

B. *Fire.*—Fires have probably been in general occurrence throughout the greater part of the upland forests, including the pine areas, from a date long preceding the advent of the early settlers. Undoubtedly these fires have limited the spread of the pine. It is well known that within the historic period many young stands of pine have developed in different parts of the basin. This is particularly true in sections of Van Buren and Cleburne Counties, Ark., as well as

other points on the basin. These stands, however, are yet too small and inaccessible to be of commercial value.

C. *Grazing.*—While fire has undoubtedly been a potent element in the determination of the character of cover on this basin, it is in connection with close grazing that the balance was decided in favor of the forest. The scattered herds of wild game roamed the bluestem pastures. The close grazing of cattle destroyed the bluestem. It is now in places even unknown as a grass, and over thousands of acres not a bunch can be found where formerly it made a sod. At present, if fires are stopped, the ranging of cattle will result in little detriment to the forest. But, unfortunately, it is assumed that the range is improved by burning.

On the whole, grazing is not a serious problem in the forest lands of this basin, although woodland grazing is almost universally practiced. Farmers' woods in some cases are overstocked with the result that the establishment of young trees is prevented, and humus can not accumulate. Exposure of naked soils follows with resulting erosion; but areas of this kind are not extensive.

Drainage has had no influence upon the upland forests of this basin since there is no drainage on the uplands; but extensive areas on the lower part of the watersheds of all of the streams in the southeastern part of the basin have been drained by straightening the channels of existing streams, by dredging artificial channels, and considerable areas have been diked to prevent flooding. This portion of these basins is largely or entirely cleared. Such of the lowland areas as have been sufficiently dried through drainage as to be used for cultivated crops have been cleared.

CRITICAL FOREST AREAS

Most of the forest lands located upon slopes and breaks along the streams should be designated as critical. The lands now in national and other public forests are being managed to serve their highest purposes as wood-producing, water-regulating properties, and should continue to do so, but while the areas of forest land on slopes are especially designated as critical on account of minimizing erosion all forest lands on the basin can be developed to performing a high function in the storage of storm water in their humus, and considerable areas not located upon steep gradients might from this point of view be held as critical.

RECOMMENDATIONS

(1) There should be a large increase in the area of public forests within this basin. In Arkansas not only should the area within the existing boundaries of the national forest be consolidated but these boundaries should be greatly extended. In the State of Missouri the present area of 41 square miles of public forest is entirely inadequate to meet the watershed protection situation.

(2) On private forest lands prevention of fire is the acute problem, and there seems to be urgent need for extending special aid to this region under the fire-cooperative features of the Clarke-McNary Act until there is a betterment in this situation.

(3) Planting is especially desirable for the protection of lands on steep slopes which have been cleared and which are not so adequately

protected by sod as to prevent excessive erosion from taking place. There are considerable areas of silty soils on Crowley's ridge on which disastrous erosion is taking place, but there are extensive areas of farm lands not now in cultivation on which erosion is high, although not so destructive as on Crowley's ridge. It is probable that these areas are so limited that there is no necessity for a special appropriation under section 4 of the Clarke-McNary Act so far as the basin of this stream is concerned, but there is necessity for a special program to be carried out by local agencies in promoting the salvage and utilization of such lands.

(4) Although the area of upland farming land on this basin is not excessively large, the major part of it is cultivated in intertilled crops, particularly in corn, and the erosion from this land on slopes is not only depleting its fertility, but is adding much to the silt burden of the river. This situation should be remedied by a campaign by county demonstrators to reach, through personal contact, individual landowners. Betterment of the condition of agricultural lands will be of benefit primarily to the landowner and to the local community.

OUACHITA RIVER

(Area 72)

LOCATION AND AREA

The Ouachita River, rising in the Ouachita Mountains of west central Arkansas, drains an area of 18,643 square miles. It joins the Tensas to form the Black River about 25 miles north of the point where that river empties into the Red River. Approximately 73 per cent of the watershed is located within the State of Arkansas and the remainder in northeast Louisiana.

The drainage of the Arkansas and Red Rivers form the north and west boundaries respectively, while the basin of the Tensas River adjoins it to the east.

TOPOGRAPHY

In general, the Ouachita River Basin is a well-drained country sloping toward the southeast, with topography ranging from mountains in the north to flat alluvial plains in the south. The maximum length of the Ouachita River drainage is about 260 miles. In outline this drainage area is roughly fan-shaped, the broadest part being near the source. This presents a condition very favorable for the quick collection of storm waters and the consequent rapid rise and flooding of the main stream.

The northern 18 per cent of the Ouachita basin is classified as mountain topography, being in the Ouachita Mountain region of the southern Ozarks. The flat alluvial lands of the Ouachita River bottoms contain 36 per cent of the total area. With the exception of a very small area of hill land, part of a considerably larger area of similar topography in the Red River watershed in northwest Louisiana, the remainder of the Ouachita Basin is rolling in character.

The elevation at the southern end of this basin is approximately 80 feet above sea level. The elevation increases gradually toward

the head of the watershed, the altitude along the southern border of the Ouachita Mountains being 500 feet. From here on into the mountains the rise is rapid, a few of the highest peaks reaching an altitude of nearly 2,000 feet. However, 82 per cent of this drainage lies below 500 feet in elevation. The slopes of the mountains are steep and contain much broken-rock material with numerous outcrops of bedrock showing.

The streams in the mountains flow swiftly over rocky beds, discharging their waters into the larger slower-moving streams in the valleys. Outside of the mountain region streams flow less swiftly, and become sluggish and tortuous in the southern part of the watershed.

The Ouachita Mountain region offers favorable opportunities for the storage of water, a condition not commonly found in the States of the lower Mississippi Valley. There are numerous valleys throughout the mountains which could be made to serve as basins for impounded water.

GEOLOGY AND SOILS

The Ouachita watershed presents a wide variety of geological formations. The soils of the Ouachita bottoms are alluvial in origin and, although they are susceptible to erosion, the lack of topographic relief removes this danger.

The soils of the interior coastal plain, which were washed down from higher ground and deposited when this region was still under water, include some soils which erode easily. Of the more widely distributed soil types the Orangeburg and Susquehanna series are the most susceptible to erosion. However, in the interior coastal plain of the Ouachita Basin there is little country that is sufficiently rough to make the soil-erosion problem serious.

Several small areas belonging to the interior flatwoods soil region occur in Arkansas, one a long narrow belt extending along the north side of the Ouachita River bottoms above its junction with the Saline River. East of the Saline and extending from just south of the Louisiana line northward along the western border of the Mississippi bottoms nearly to the Ouachita Mountains is another belt of the flatwoods. The soils of this region are clays and clay loams, but due to the flat and poorly drained nature of the country, they are not in danger of erosion.

Of the entire Ouachita watershed, the mountains in the north present the most critical conditions from the viewpoint of soil conservation. These mountains consist largely of hard sandstone ridges running generally in an east and west direction, with considerable more easily weathered shale present in the valleys. Soils form a thin covering over the rock and are often mixed with broken rock fragments. The predominant soil type, Hanceville stony loam, is derived from the underlying sandstone and shale.

Drainage is excessive over much of the hill section. The run-off is rapid and much soil washing takes place.

Hanceville stony loam is the prevailing soil type on the rougher land. This type occurs on many steep slopes where run-off is rapid and destructive. Here, clearing and cultivation would result in severe erosion; consequently the slopes should be kept in timber.

CLIMATE

The mean annual precipitation is 50 inches, of which slightly more than half occurs during the warm season. About 16 inches of rain usually falls in March, April, and May. In 1927 about 16 inches fell during March and April. On the whole, precipitation is medium, except in the region of the headwaters in the Ouachita National Forest and for a small area near the mouth of the river, where it approaches the maximum for the South.

On this watershed the normal annual temperature varies from 62° at the source to 67° at the mouth of the river. The January normal is about 45° and that for July above 80°. Snow covers the ground for less than a week each year.

HISTORICAL DEVELOPMENT

Agriculture and lumbering are the leading occupations in the Ouachita drainage. General settlement for agriculture began in the early years of the nineteenth century (as early as 1769 in Ouachita Parish, La.) and progressed slowly until 1830 and more rapidly after that date. Extensive lumbering in excess of local needs began between 1890 and 1900; since then it has increased greatly in scope and importance, in both pine and hardwood forests, particularly in Louisiana. Only about 55 per cent of the land in the drainage is in farm ownership, the balance mainly in the hands of lumber companies except for the Hot Springs National Park and part of the Ouatchita National Forest near the headwaters of the Ouachita River in Arkansas.

There are no stock laws in either State in which this drainage lies, and tradition leads farmers and stockmen to burn over annually the open range on which their herds graze, regardless of ownership of the land.

Originally about 21 per cent (3,892 square miles) of the Ouachita drainage was in bottom-land hardwoods, and 79 per cent (14,751 square miles) in the pine type. Because of more rugged topography, more remote markets, and more limited financial resources, the development of lumbering in Arkansas has lagged behind that in Louisiana. On this account relative amounts of forested, unimproved, and improved lands vary for each State as well as for different forest types. Thus, in the bottom-land hardwoods type in Louisiana, 44 per cent (1,136 square miles) of the area is in forest, 38 per cent (981 square miles) in unimproved land, and 19 per cent (465 square miles) under cultivation; whereas in Arkansas 60 per cent (786 square miles) is in forest, 21 per cent (275 square miles) in unimproved land, and 19 per cent (249 square miles) under cultivation. In like manner 24 per cent (612 square miles) of the land within the boundaries of the pine type in Louisiana is in forest, 57 per cent (1,455 square miles) in unimproved lands, and 19 per cent (485 square miles) in cultivation; whereas in Arkansas 67 per cent (8,173 square miles) is in forest, 18 per cent (2,196 square miles) in unimproved land, and 15 per cent (1,830 square miles) under cultivation. To sum up, in both Louisiana and Arkansas about a fifth of the original forest land in each type has

been cleared for agriculture. Of the balance, three times as much of the pine land and half as much again of the hardwood land has been logged off in Louisiana as in Arkansas.

CONDITION OF LAND OTHER THAN FOREST

Within the boundaries of the pine type, corn and cotton are the principal crops, and the minor crops resemble them in being open grown and intertilled. On sloping ground and on soil naturally subject to erosion this characteristic contributes directly to soil washing and rapid run-off. On the steepest slopes and most easily washed soils terracing is needed, but unfortunately is seldom practiced. Contour plowing, which to a certain degree prevents soil losses, is practiced on a large part of the erodible area in the Louisiana portion of the drainage and on practically all of the Arkansas portion. The improved land in the pine type is rated at 75 in Louisiana and at 80 in Arkansas; 76 is the average for the type.

Within the boundaries of the bottom-land hardwoods type cotton is the principal crop; corn ranks second. Both are open grown and intertilled, as in the type previously described, but here the flat topography prevents erosion. The average rating for the entire type is 92.

The unimproved land within the borders of the pine type in Louisiana includes a small proportion of abandoned cultivated land and a very large amount of cut-over pine land which has been burned annually or nearly annually for many years. Fires rather than grazing or lumbering have been the chief cause of damage; without fire most of this cut-over land would have come back to shortleaf and loblolly pines and hardwood brush or to a heavy protective cover of grass. As it is, the unimproved land in this portion of the type in Louisiana rates only 55 from the standpoint of erosion and flood control. In Arkansas, fires have not been quite so common, and therefore have caused less damage. Here the unimproved areas are more often found to be restocking to pine or a brush cover, and the cover is rated 65. The average for the type is 61.

Within the boundaries of the bottom-land hardwoods type in Louisiana there is a small amount of recently abandoned, cultivated land, and a very large amount of cut-over hardwood land, the greater part of which has burned over at intervals of from 3 to 10 years. As compared with burning, grazing has done little damage. The natural tendency of such land is to revert to hardwoods, brush, or heavy grass, but under present conditions of periodic fires much desirable forest vegetation is hindered and the accumulated organic matter destroyed. Therefore the cover is rated at 75. In Arkansas, conditions are somewhat better, and the same type of cover is rated at 80, making an average rating, within the type, of 76.

CONDITION OF FOREST

The pine type has been more nearly cut out in Louisiana than in Arkansas, and the timber left standing has been more severely burned. A small area of long-leaf pine occurs in the southern part of the Louisiana portion, and this has suffered most of all, principally

from fire and hogs. The stand is generally open, with little brush or ground cover, and very little reproduction has taken place. North of the longleaf area the forest is largely shortleaf and loblolly pine, with an increasing mixture of upland oaks and hickories toward the Arkansas line. Part of the land classified as forest is in young second-growth shortleaf which established itself naturally where conditions of burning permitted. Shortleaf and loblolly approach their optimum development in this region and if given a chance would form an excellent protective cover. Because of fire damage, especially in the long-leaf area described above, the portion of the pine type in Louisiana is rated only 75. North of the Arkansas line much less pine has been cut out and, despite periodic (3 to 10 years) burns over much of the area, the shortleaf-loblolly pine forest affords a better cover than in Louisiana. Seventy per cent of the remaining pine forest in the drainage lies in Arkansas. Shortleaf is the dominant species. Reproduction is often excellent, and part of the forest area is in young second growth not yet large enough to cut except for pulpwood. Hardwoods form an increasingly important part of the stand toward the north, especially on the north slopes. The rating given the Arkansas portion of the pine type is 80, making an average of 80 for the type in the Ouachita drainage as a whole.

The bottom-land hardwoods type consists principally of red gum, white ash, red, white, and water oaks, and, in very restricted areas, cypress and tupelo gum. The cypress has been largely cut out from the brakes where it occurred originally. These brakes are reproducing to cypress, tupelo, and red maple, in varying degrees. A great number of miscellaneous hardwood species also occur in the bottom-land hardwoods type but are relatively unimportant at present. Part of the land classified as forested is in second growth or is covered by remnants of selectively logged stands. Fires occur every 3 to 10 years on much of the area in both Louisiana and Arkansas, periodically consuming all of the litter even though they do not kill the trees. Litter may attain a depth of one-half to 1 inch on unburned sites. Due to its rapid decomposition leaf litter becomes integrated with the soil with two or three years after it has reached the ground.

As a whole the forests of this type constitute a good protective cover and have an average rating of 95, but their location makes them ineffective in controlling run-off and erosion.

CRITICAL AREAS

Critical areas within this drainage include the Ouachita Mountain district in west central Arkansas and a small strip of hilly country in northern Louisiana, in each of which, because of the rugged topography, soil wash is excessive when cover conditions are disturbed by clear cutting and burning the forest or when agricultural methods fail to provide for the prevention of soil wash. As a matter of fact, the greater part of these areas is still under forest cover, especially in the Ouachita Mountain region, occupied in part by the Ouachita National Forest.

Each of the critical areas just mentioned is but a portion of more extensive areas in adjacent watersheds where similar conditions

FIGURE 17.—Five years after logging in saline bottom, Arkansas. Close cutting had brought in briars and tall herbs, but cow oak, sycamore, sweet gum, pin oak, persimmon, etc., have reproduced abundantly. Ouachita River watershed

FIGURE 18.—Results of cutting pulpwood in an old field of shortleaf pine, 18 years old, where the trees ranged from 2 to 10 inches D. B. H., average 6 inches, and where 20 cords per acre were removed 6 months ago leaving smaller trees for the next cutting. Ouachita River drainage

FIGURE 19.—Fire in hardwood bottom, Oak Grove. Ouachita River drainage

FIGURE 20.—Fire damage to black oak, 65 years old. Oak Grove. Ouachita River drainage

FIGURE 21.—Cut-over and burned-over cypress and tupelo brake, burned in 1924. Ouachita River drainage. Bottomland hardwood

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FIGURE 22.—Highway cut into loess and sandstone near Enterprise, La. Loblolly-shortleaf type. Ouachita River drainage

exist. The fact that a fair protective cover is already present in the Ouachita Mountains would make this region one of beneficial influence as a means of controlling run-off and soil erosion if the ground cover had been kept in good condition. This, however, has not been the case. Woods fires have been common in the past and even now considerable areas are burned over annually notwithstanding the efforts of the national forest organization and some private lumber companies to give protection to their lands. Because of this fact, the critical area in the Ouachita Mountain region of this watershed has been classed as neutral in its effect on floods in the Mississippi River Basin. Although conditions in northern Louisiana are even worse than those in Arkansas, the critical area located in this part of the watershed is so small that its detrimental influence is obscured in the average rating for the entire watershed, which has been placed at 71.

RECOMMENDATIONS

The mountainous region in west central Arkansas is so rugged and on the whole so unsuited to agriculture that it should always remain in timber, not only because this represents its most productive use, but also because of its value as a protection forest. The management of this true forest land will necessitate an adequate system of fire protection and methods of cutting which will leave a stand of trees continuously on the ground. Planting of denuded areas may be necessary in a few localities if this proves to be the most feasible method of reestablishing a soil cover. Research will be needed in the study of these problems.

Extensions of Federal ownership to lands adjacent to the present national forest area should be made wherever such action would assist in obtaining more unified administration and protection. Farming should be encouraged on land which is best suited to agriculture, if the methods used in tilling the soil are such as to prevent excessive erosion. Such methods are now being demonstrated extensively by county agricultural agents. The value of fire prevention measures should be particularly stressed and in this the national forest organization can well take the lead, especially as no State department of forestry has yet been created. The prompt creation of such a department, because its existence would make available Clarke-McNary funds, would greatly facilitate fire protection on private lands.

RED RIVER DRAINAGE BASIN

(Area 73)

LOCATION AND AREA

The Red River watershed, occupying 69,548 square miles, heads in eastern New Mexico, extends eastward across the Panhandle and along the entire northeastern border of Texas, into southern Oklahoma and southwest Arkansas, thence into Louisiana, where it terminates near the Mississippi River. The basin as a whole slopes to the south and east and is approximately 750 miles long. In no place does it exceed 170 miles in width. The Arkansas and Ouachita

River basins form the north and east boundaries respectively. To the south lie a number of streams draining directly into the Gulf of Mexico, chief of which are the Atchafalaya, Sabine, Neches, Trinity, and Brazos Rivers.

TOPOGRAPHY

The Red River Basin exhibits a great variety of topographic conditions. The elevation ranges from approximately 80 feet above sea level at the eastern end of the watershed to nearly 5,000 feet in eastern New Mexico. Twenty per cent is flat land, half of which occurs in the alluvial flood plains of the river bottoms and half in the high level plains west of the "Breaks" in the Texas Panhandle. Mountainous regions comprise 8 per cent of the watershed, the largest single unit being the Ouachita Mountains of southwest Arkansas and southeast Oklahoma. The elevations here vary from 500 feet up to nearly 2,000 on the highest peaks and ridges. The Arbuckle and Wichita Mountains located in south central and southwest Oklahoma, respectively, comprise comparatively small areas of mountain country. The elevation of the Arbuckle Mountain region ranges from 750 feet in the east to 1,350 near the western end of the range, while the Wichita Mountains reach an elevation of over 2,000 feet. Hilly land, practically all of which is located in northwest Louisiana, occupies but 3 per cent of the watershed and averages well below 500 feet in elevation.

The remainder of the Red River Basin (with the exception of the severely eroded "Breaks," which occupy 6 per cent of the total drainage) is classified as rolling land.

Drainage, except in the small area of very low land near the mouth of the Red River, is very good throughout the watershed. Streams as a rule have sandy or silty beds, although considerable rock is found in the courses of the mountain tributaries and in places in the streams on the plains and prairies. The Red River carries a heavy load of silt, the chief source of which is the severely eroded "Breaks" near its headwaters.

GEOLOGY AND SOILS

In the Red River Basin west of the East Cross Timbers soil region (which lies in north central Texas) are found the following six generally recognized soil divisions: The High Plains, Breaks, Red Prairies, Eastern Prairies, West Cross Timbers, and Edwards Plateau. Geologically these can be grouped into the Great Plains region.

The underlying formations consists of limestone, sandstone, shale, wind-blown formations of the Rocky Mountains in the past and deposited over a wide area by shifting streams. The principal soils of the High Plains of the Texas Panhandle are derived from this outwash and consist mostly of silts or clays. East of the High Plains (in the Breaks, Red Prairies, and Edwards Plateau) are large areas the soils of which are derived from sandstone, shale, and limestone and deposited by streams over the valleys and lowlands. Loams, clays, and clay loams predominate. Areas in this same region not covered by this outwash consist of residual material from the Permian Red Sandstone in the Red Prairies and underlying limestone in

the Edwards Plateau region. In the West Cross Timbers and Eastern Prairies soil are mainly residudal, having been formed from underlying sandstone, shale, and limestone, the sandstone being the principal origin of the West Cross Timber soils.

All of these soils, and particularly those with a low sand content, are more or less susceptible to erosion. However, the rolling character of the topography, combined with relatively low rainfall, counterbalances this danger.

There is but one main area in this Great Plains region which can be called critical from the viewpoint of soil conservation. This area, known as the "Breaks," is located largely in the Texas Panhandle east of the High Plains but also extends into western Oklahoma. Here erosion doubtless started at the steep escarpment separating the High Plains from the lower Red Prairies, and proceeded back along the watercourses until now there are wide belts of severely eroded country along most of the larger streams.

This scarp rises abruptly 200 to 500 feet above the eroded plains to the east. In some places the slope is more gradual and occupies a belt of land 5 to 6 miles wide—a belt marked by distinct topographic features in contrast to the flatter plains to the east and west.

This escarpment is known locally as "The Breaks." It occurs along the margins of valleys and passes from one drainage system to another in broad eastward-looping curves. It is characterized by bad-land erosion forms, short ridges, steep talus slopes, isolated buttes and peaks, and an intricate system of narrow V-shaped valleys that sometimes develop into impassable canyons.

Many small streams rise in the edge of the High Plains. Some of the larger streams reach far back into this section and make its eroded margin very irregular in outline. The surface of the High Plains beyond the eastern border is unaffected by erosion in the narrow canyons and the unbroken land extends almost to the brink of the canyon walls.

The nutritious prairie grasses of the native sod, covering an extensive open range, have rendered the section well suited to cattle raising. No other industry is as well suited to the "Breaks."

The interior coastal plain soils region occupies most of the Red River watershed in Louisiana and northeastern Texas. The soils of this district consist of water-lain material brought down from the higher lands to the north by the streams of the region. This material was emptied into the ocean which covered the land at that time. The finer particles were carried farthest out to sea and deposited in deep or quiet waters giving rise to the present areas of clay lands. The black waxy belt, lying east of and adjacent to the Eastern Cross Timbers region, is a good example of this type of formation. The soils of the interior coastal plain are, for the most part, fine sandy loams, silt loams, and clays. Susquehanna, Norfolk, and Orangeburg soils predominate in the interior coastal plain region of the Red River Valley. The Susquehanna fine sandy loam is underlain in many places by a stiff, impervious subsoil which makes it susceptible to destructive washing on steeper slopes. Considerable areas in Titus, Camp, Morris, Upshur, Marion, and Cross Counties in extreme northeastern Texas are covered with this soil and some serious erosion has taken place. This region is a pros-

perous agricultural district and improved methods of cultivation will go far toward remedying this condition. Similar areas are found in the hilly district of Webster, Clairborne, Bienville, Lincoln, and Winn Parishes in northewestern Louisiana. However, this latter region is largely a cut-over timber country and comparatively little agricultural development has taken place.

A third area where there is danger of excessive soil wash is in the hills of Natchitoches and De Soto Parishes, La. The well-known Kisatchie Hills lie within this region and topography, more than soil, makes this district susceptible to soil washing.

The Ouachita Mountans of Arkansas and Oklahoma occupy parts of both the Red and Ouachita Rivers drainages, and the same geological formation and soils are found in each of these watersheds. These mountains form a broadly wedge-shaped extension reaching westward into Oklahoma to a point nearly 100 miles west of the Oklahoma-Arkansas State line. The ridges extend in a general easterly and westerly direction and are comprised of hard sandstones with shales in the valleys. Hanceville soils are the chief derivatives with the stony loam phase occupying the steeper and more easily eroded slopes. These soils form a comparatively thin covering and contain much broken rock material, occasional outcrops occurring.

Concerning this region, G. R. Phillips, present State Forester of Oklahoma (1927) states: "Much of the land when cleared is so subject to erosion that only a comparatively few crops can be raised before it has to be abandoned."

The Arbuckle and Wichita Mountains in southern Oklahoma have essentially different geological formations. The Arbuckle Mountains consist of narrow, level-topped, hard-limestone ridges which have resisted weathering to a much greater degree than have the softer chert and shale formations in the valleys. This difference in resistance to weathering is the primary cause of the local topographic relief. Slopes that are cleared for cultivation wash so badly that they are soon abandoned. Although clearings are not abundant, they comprise an important and conspicuous part of the total area.

The Wichita Mountain region is composed chiefly of igneous rocks, mostly granite, although some of the border ranges consist of hard, limestone formations. This latter type, which probably once covered the entire region, has largely weathered away and exposed underlying granitic rocks. The soils derived from this limestone are very susceptible to erosion, but taking the region as a whole, topography is the greatest contributing factor to soil washing.

The alluvial plains of the Mississippi bottoms and the flood plains of the Red River and its larger tributaries contain large deposits of silt and clay. The texture of these soils is such that they would be subject to severe erosion were it not for the lack of topographic relief.

CLIMATE

The mean annual rainfall in the Red River Basin ranges from less than 20 inches at the extreme western end to 55 inches at the mouth of the river. The change in amount of precipitation from west to east is gradual and uniform. Throughout the area somewhat more than half the total occurs during the warm half of the year. During the spring quarter—March, April, May—precipitation usually ranges

from 5 inches at the source to 15 inches at the mouth, but in 1927 this much fell in March and April alone. The average precipitation may be classed as light in the western portion and as medium in the eastern portion.

The normal annual temperatures along the Red River drainage vary from 59° F. at the source to 68° at its mouth. The January normal varies from about 30° at the source to nearly 50° at the mouth. The July normal is above 80° except in the Panhandle of Texas, where it drops to 75°. Snow covers the ground for less than a week over most of the basin, although in the Panhandle region of Texas there may be 10 or 15 days of snow during a year.

HISTORICAL DEVELOPMENT

A varied political history has combined with great climatic and physiographic differences to produce the present diversified conditions in the Red River drainage. Changes in national ownership have influenced the time, rate, and amount of settlement, which in turn have affected agriculture and lumbering and hence the present condition of the land with regard to protective cover.

The southernmost portion of the drainage was first settled by the French under French rule. Natchitoches, in Natchitoches Parish, La., dates from 1714, and before 1800 settlement had taken place along most of the river fronts in neighboring parts of the drainage. The parishes farther north, together with the adjacent counties in Arkansas, were settled under American rule at or shortly after the Louisiana Purchase (1803), and from about 1830 on their development was fairly rapid.

As far south as the Atchafalaya Basin the southern boundary of the Red River drainage constituted the original southern boundary of the land included in the Louisiana Purchase, but in 1819 a compromise treaty reestablished the boundary at the Red River itself as far west as the one hundredth meridian, and along that meridian north to what is now Dodge City, Kans., on the Arkansas River. The portion of the Red River drainage in what is now Texas was thus removed from the jurisdiction of the United States. Nevertheless, settlements were soon established in the Red River Valley on the Texas side (Lamar County in 1820 and Grayson County in 1827), and shortly after 1830 the country farther south (Franklin, Titus, Morris, Camp, Harrison, and near-by counties) was opened up and agricultural development begun. The "Republic of Texas" was annexed by the United States in 1845, and from then on the eastern end of the Texas portion of the drainage developed rapidly. The Federal Government owned no public land in Texas, all public domain of the Republic of Texas having remained the property of the State of Texas, and hence the Federal homestead laws did not affect the course of development of the region. Deficient rainfall was probably the main barrier to the westward spread of agricultural settlement.

About 1870, however, cattle ranches became generally established through the Red Prairie region of Texas (one hundredth meridian) and in the early eighties they invaded the High Plains region (Staked Plains) west of the Breaks (one hundred and first meridian and westward). At first, cattle were supported entirely on open range,

but in the latter eighties sorghum was first raised for winter feed. Since that time the cattle industry has undergone profound changes. The Fort Worth & Denver Railway was put through the Panhandle in 1887 and accelerated the first of these changes by stimulating the development of farming. The establishment of other railroads resulted in a very general cutting up of large ranches into smaller farms, with a consequent increase in the area of cultivated land. Most of the public lands of the State were now sold to or homesteaded by farmers. Land values have risen ever since. Graded or purebred Herefords have replaced the Texas longhorns which were the mainstay of the original ranches, and increasing use is made of the coarse forage crops for feed. In 1925 approximately 24 per cent of the land in the Red Prairie and High Plains region was in cultivation, marking an increase of from 1 to 9 per cent of the total land area in each county since 1920. (The same period was characterized by a universal decrease in cultivated areas farther east.) The closer grazing which in some places has resulted from the modern intensive methods of cattle raising seems to have increased somewhat the erosion among the Breaks and, combined with the almost total elimination of prairie fires, to have permitted the invasion of former grasslands by brush.

To sum up the Texas portion of the Red River drainage, despite some delay prior to its becoming a part of the Union, has developed over a long period of years, in normal response to economic stimuli, and practically uninfluenced by any political or agrarian program of the Federal Government. The eastern part, originally forested but settled comparatively early, now shows the results of nearly a century of agricultural exploitation. Here the most conspicuous change has been the reduction of forest area and its replacement in large part by cultivated land. The more recently settled western part, beyond the limits of forest growth in the ordinary sense, has been changed principally by the cultivation of a quarter of the land area and a reduction of the grass cover on the remainder by more or less intensive grazing.

While Texas was changing hands and developing as outlined above, the present State of Oklahoma remained uninterruptedly in the possession of the United States and for many years was kept practically unsettled. The eastern part was known as Indian Territory; the western as the Territory of Oklahoma. This vast region, extending far north of the Red River drainage, was opened to homestead in 1889–1892, and a great rush of farmers poured in to take up the productive and easily acquired land. Naturally the prairies, already open, and the bottoms, immensely productive upon being cleared, were taken first, and to this day there has been less agricultural development in the upland post-oak region than in the open grasslands. Development in the mountainous portion of the drainage included in the pine type of southeastern Oklahoma has been at a minimum, less than 30 per cent of the total area being in farms. As a result, the Oklahoma and Texas portions of the drainage which lie within the upland hardwoods—long grass association (discussed below) have nearly equal percentages of their area in cultivated land and in woodland and forest, but the cultivation is of much longer standing in Texas. In the pine type there is an even more striking

contrast between these States, the Red River separating well-established agricultural communities in Texas, where only 32 per cent of the land is left in forest, from a virtual wilderness in Oklahoma, where 70 per cent of the land remains in pine.

Too minute a fraction of the Red River drainage lies in New Mexico to make the history of that State of any interest here.

CONDITION OF LAND OTHER THAN FOREST

Of the 69,548 square miles in the Red River drainage, approximately 28 per cent (19,083 square miles) lies within the boundaries of the pine type, 5 per cent (3,647 square miles) within those of the bottom-land hardwoods type, and 67 per cent (46,818 square miles) within those of what is nominally the upland-hardwoods type. Actually this last-named type marks a complicated transition from an upland hardwoods-pine type and mixed hardwoods type in eastern Texas and Oklahoma through the post-oak type of the East and West Cross Timbers, with their interspersed prairie grasslands, to tall grass, desert savanna, and finally short grass associations in the west, with their small but significant representations of willow and plum along the stream beds and of mesquite and shin oak on the level plains above. Detailed descriptions of the subdivisions of the upland-hardwoods type, so called, will be given in the following discussion of cultivated and unimproved land.

The principal agricultural products within the boundaries of the pine type in the Red River drainage are corn and cotton, both intertilled crops which, when grown on hilly land, expose the soil to danger of erosion. In Arkansas contour plowing is almost universal; in Oklahoma, Texas, and Louisiana it is less generally practiced. There is need of terracing on the steeper slopes in all four States, but since little terracing is actually carried out, the rating of the cultivated land (from the standpoint of controlling run-off and erosion) is put at 75 in Arkansas, at 70 in Oklahoma and Texas, and at 70 in Louisiana except in the Little River portion of the drainage, where it is put at 65. In the Arkansas portion of the pine type cultivated land occupies 1,049 square miles (25 per cent of the total area), in Oklahoma, 466 square miles (11 per cent), in Texas 923 square miles (30 per cent), and in Louisiana 949 square miles (19 per cent) in the Red River drainage proper and 206 square miles (only 8 per cent) in the Little River tributary drainage.

Within the boundaries of the bottom-land hardwoods type the principal crops are cotton and corn; sugar cane and miscellaneous crops are of increasing importance toward the extreme southeastern tip of the drainage in Louisiana. All these crops leave the soil exposed to washing, but because the bottom lands, especially to the south, are not subject to rapid draining of water, and because tillage increases the water absorptive power of the soil, the cultivated land is given a rating of 95 in Louisiana and of 90 in Arkansas, Texas, and Oklahoma. The area of cultivated land in this type in the Red River drainage (including the Little River) is approximately 908 square miles; this is 25 per cent of the total area within the type.

Considerable variation characterizes the distribution and character of the unimproved land in the pine region of the Red River drain-

age. In Louisiana, longleaf is the dominant species in perhaps half the pine type within the Little River tributary drainage and in a third of the pine type within the drainage of the Red River proper. Here the exploitation of timber resources has greatly exceeded agricultural development, and as a result there are vast areas of clear-cut, fire-swept land exerting very little protective influence. On the remaining pine land, which was originally in shortleaf and loblolly pine with an admixture of hardwoods, logging has been less destructive and burning somewhat less severe; more young pine, oak brush, and grass have come in to cover the ground, and consequently the protective value of the unimproved land is higher. In the Louisiana portion of the drainage as a whole the unimproved land covers approximately 57 per cent (4,348 square miles) of the area in the pine type and has a rating of only 57. The unimproved land in the pine type in Arkansas, Oklahoma, and Texas resembles the better class (shortleaf, loblolly, hardwood) described above, being most severely burned in Oklahoma, including more eroded and abandoned farm land in Texas; and being least burned in Arkansas, in part because of the fire protection work on the Ouachita National Forest and on the extensive holdings of one or two progressive lumber companies. In Oklahoma it covers 19 per cent (806 square miles) of the land within the type, and is rated at 70; in Texas, 38 per cent (1,168 square miles), with a rating of 70; and in Arkansas 16 per cent (671 square miles) with a rating of 75. The total for all variations of the pine type in the drainage as a whole, in four States, is 37 per cent (6,993 square miles), with an average rating of 71.

The unimproved land in the bottom-land hardwoods type varies somewhat from State to State in the amount of burning it suffers, and in the amount of protective grass and brush it supports; on the whole it is in better condition than the cut-over land in the pine type and, because it does not occur on any critical areas, it may be dismissed briefly. It occupies 39 per cent (1,419 square miles) of the total bottom-land hardwood area lying in the Red River drainage of Louisiana, Arkansas, Oklahoma, and Texas, and has an average cover rating of 83.

The portion of the Red River drainage in which upland hardwoods constitute the dominant or only woody growth falls naturally into three subdivisions distinguished by the dominant grasses. The easternmost is the tall grass region, which covers practically all of the Oklahoma portion of the drainage west of the pine region and all of the Texas portion between the pine region and the eastern Red Prairies. This subdivision contains practically all of the true timber in the upland hardwood type, including, as it does, the transition types (mixed upland hardwoods, post oak) mentioned above, alternating with grassy prairies. Its total area is 28,483 square miles. The other two subdivisions are the desert savanna, covering 6,898 square miles in Texas between the eastern Red Prairies and the eastern Breaks, and the short-grass association, covering 11,437 square miles in extreme southwestern Oklahoma and in Texas, west of the Breaks.

The great prairie region of the Mississippi Valley and the small isolated prairies through the eastern part of the United States and along the Gulf coast are characterized by tall, luxuriant, deep-rooted

grasses in mixture with a great variety of herbaceous flowering plants. The prairie was one of the most distinctive features noted by the emigrants to the West.

The moisture supply of most of this area comes largely during the growing period and varies from about 20 to 40 inches. In the drier portions the soil moisture extends to a depth of several feet and to ground water in the moister sections. The subsoil of most of the area is permanently moist, but along the western edge the subsoil is permanently dry and the soil is moistened only to a depth of from 2 to 4 feet. During the late summer and fall the luxuriant growth of grasses sometimes exhausts the supply of moisture within reach of the grass roots and droughts follow. During drought periods in the past the area was burned repeatedly by fires which were started by Indians, travelers, or lightning. These fires often occurred in late summer or winter and doubtless have been a factor in preventing forest growth on the land. In some places fires in the forests themselves destroyed the trees and enabled the grasses to establish themselves. In the eastern portion of the area fires probably protected the grassland from the encroachment of the forests. Trees and shrubs are killed by fires and as a consequence the grasses are able to establish and maintain themselves on potential forest land. Since the settlement of these lands and the consequent checking of the prairie fires tree growth has been gradually extended, by both planting and natural seeding, so that trees now are found throughout the prairie region.

In the subdivision in which the tall-grass associations are dominant, woodland and forest (rated at 80) occupy 19 per cent (5,412 square miles) of the total area; unimproved land (rated at 70), 40 percent (11,393 square miles); and cultivated land (rated at 75), 41 per cent (11,678 square miles). The total cover rating of the subdivision is 74.

The desert savanna type is characterized by a short-grass cover which grows under and between scattered small trees or thorn bushes. Usually the beginning and the end of the growth period are determined by available moisture. Temperature plays but a small part in limiting the growth of the natural vegetation. The distribution of water throughout the season is somewhat similar to that in the desert region. Although the rainfall is relatively heavy, the high temperatures and the high-saturation deficit of the air subject the plants to extreme drought conditions. Over much of the area most of the rainfall occurs in the spring and summer, during the period of greatest growth. Portions of the area receive less than 20 inches of rain annually, but in the east it runs to as high as 30 inches. The evaporation rate is high. This savanna occurs in Texas south of the Red River and mostly south and east of the Plains border.

In the desert savanna subdivision 3 per cent (207 square miles) of the total area, rated at 85, is in woodland; 72 per cent (4,967 square miles), rated at 75, is unimproved land; and 25 per cent (1,724 square miles), rated at 75, in cultivated land. The total cover rating of the subdivision is 75.

The Great Plains east of the Rocky Mountains and west of the one hundredth meridian are characterized by short grasses which are low growing and shallow rooted, owing to a low precipitation,

which falls largely just before and during the growing season. Usually the grass cover exhausts this moisture before it can penetrate more than 2 feet into the soil. A layer of carbonate accumulation in the soil at a depth of from 8 to 20 inches marks the depth of the periodically moist surface soil layer. There is no storage of available soil moisture from year to year, and the subsoil is permanently dry. Therefore the growth of deep-rooted plants is impossible. The period of no frost varies from about 100 to 200 days, but the growing season of the short grasses seldom exceeds 90 days.

Dry farming has been tried in nearly all parts of the short-grass region, but it has been profitable only in the less arid portions. The soil is productive under irrigation; cereals, alfalfa, sugar beets, potatoes, and other vegetables have been grown with most success. This region is not thickly settled. Most of the land is in farm ownership.

In the short-grass subdivision, 2 per cent (229 square miles) of the total area, with a rating of 85, is in woodland; 75 per cent (8,578 square miles), with a rating of 85, in unimproved land; and 23 per cent (2,630 square miles), with a rating of 75, under cultivation. The total cover rating for the subdivision is 83.

CONDITION OF FOREST

In Louisiana longleaf pine occurring in nearly pure stands is the dominant species throughout the southern half of the pine type in the Little River tributary drainage and the southern third of the type in the Red River drainage proper. Fires occur annually in most of the forested area; as a result the stands are open, free from reproduction and brush, have only a light grass and herbaceous ground cover, and often are without even the inch or so of litter characteristic of southern upland forests. Further north longleaf gives way to loblolly and shortleaf pines, either pure or in mixture with oaks and other hardwoods. Here fires, although still very frequent, do not occur quite so often, there is more brush, grass, and litter, and the forest as a whole affords better protection against run-off and erosion. There are no stock laws. Nowhere is grazing directly responsible for much damage to the forest cover, but most of the fires are set by stockmen and farmers because of a mistaken belief that burning improves the range.

In the Little River tributary drainage the two phases of the pine forest cover 26 per cent (671 square miles) of the total area within the type boundaries, and in the Red River drainage proper they cover 47 per cent (7,826 square miles). The average rating in both drainages is 75. In the Arkansas and Texas portions of the Red River drainage the pine forest resembles that in the northern part of the Louisiana section, except that in Arkansas there is even less burning, partly because of the fire-protection work on the Ouachita National Forest and on the extensive holdings of one or two progressive lumber companies in that region. In the Arkansas portion of the drainage 59 per cent (2,476 square miles) of the area within the boundaries of the type is still in forest and rated at 78; in Texas only 32 per cent (984 square miles) is forested, but in better condition than similar land in Arkansas, so is rated at 85. In Oklahoma 70 per cent of the area (2,968 square miles) within the type boundaries is still

in forest, but poorer stands and more frequent fires combine to reduce the rating to 75.

To sum up, approximately 44 per cent (8,497 square miles) of the area within the boundaries of the pine type is in forest. The protective value of this forest is highest in Texas, somewhat lower in Arkansas, and lowest in Louisiana. Of the forested area in the Texas portion, 75 per cent is in farm woodlots; in Louisiana, 67 per cent; in Arkansas, 40 per cent; and in Oklahoma only 18 per cent. The remainder in each State is in the hands of lumber companies except for the national forest holdings in Arkansas. According to H. H. Lane [1] there are about 1,500,000 acres in the Ouachita Mountains in Oklahoma reserved from allotment, and hence presumably still part of the public domain. It has not been possible to verify this assertion.

The bottom-land hardwoods type in the Red River drainage include red and tupelo gum, cypress in varying quantities, red, white, water, and other oaks, and a variety of other hardwoods. Toward the westernmost extension of the type in Texas and Oklahoma, cypress almost disappears, the gums become of less importance, and the oaks become dominant. This type, although burned at intervals of from 3 to 10 years over much of the region, has not suffered from fire as much as have the pine forests. Generally the undergrowth is heavy and leaf litter often accumulates to a depth of an inch. Where levees have cut off the natural drainage, some areas, especially in Louisiana, are swampy the year round, and together with other districts throughout the type are subject to overflow. No information is available concerning damage done by drainage. Grazing damage is negligible. Land actually in forest varies from 28 per cent of the total within the type in the Louisiana section of the Red River drainage proper to 50 per cent of the total in Arkansas, Texas, and Oklahoma; but the average for the drainage as a whole is 36 per cent (a total of 1,320 square miles) with an average rating, from the standpoint of flood control, of 98. The location of this highly protective cover, however, is such that it has little, if any, actual effect on floods.

The absolute and relative areas of woodland and forest in the tall grass, desert savanna, and short grass subdivisions of the upland-hardwood type, together with their cover ratings, have been given in the discussion of unimproved and improved land. Some comment on the character of the forest seems desirable, however, not because the present area in forest is large, but because two critical areas (the Arbuckle Mountains and Wichita Mountains) lie within the tall-grass subdivision, and a third (the Breaks) occupies a small part of the same subdivision and very considerable parts of the desert savanna and short-grass subdivisions. The question of tree planting and other forestry measures on these critical areas is certain to be raised.

The eastern border of the tall-grass subdivision is excellent timber country. The upland oaks and the hickories predominate, but other hardwood species, to the number of three dozen or more, occur more or less commonly, together with a scattering of short-leaf pine. Toward the west, however, only a few species persist, and most of

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[1] University of Kansas, Naturalist's Guide to the Americas, 1926.

these occur only in the river bottoms and along streams. As far west as the East and West Cross Timbers a few of the oaks, elm, one or two ashes, willows, and plums occur along the streams; the uplands of the Cross Timbers are covered almost exclusively with post oak. Between and beyond the Cross Timbers are great expanses of unbroken prairie. The Arbuckle Mountains, north and east of the Cross Timbers, support a growth of scrub oak, juniper, and redbud, with elm, osage, orange, hickory, pecan, hackberry, honey locust, river plum, pawpaw, mulberry, sycamore, willow, and cottonwood in the valleys and along the streams. The Wichita Mountains, farther west, are practically treeless, supporting only a little juniper and scrub oak. In the westernmost extension of the tall-grass subdivision in Oklahoma practically the only woody species found are shin oak on the prairies and willow, cottonwood, hackberry, and plum along the streams. In the westernmost extension in Texas the shin oak is supplemented by mesquite.

Throughout much of the tall-grass region fires still occur every 3 to 10 years on a considerable part of the unimproved and wooded areas, especially on those not in farm ownership; but, as noted in the discussion of unimproved land, fires are on the decrease and the brush and forest often encroaches on the grassland. In the eastern, better-timbered section, forest fires are an important cause of erosion.

It is significant that, except in the westernmost counties in Oklahoma, practically all the county agents who expressed an opinion on the subject (in answer to a questionnaire submitted in August, 1927) believed that extensive tree planting on lands not needed for cultivation would materially decrease erosion.

In the desert savanna subdivisions the scrub and shin oaks of the uplands are augmented considerably by mesquite, which occurs abundantly over large areas, in sizes suitable for fence posts. Willows, cottonwood, elm, hackberry, and wild plum occur in the bottoms. Several species of deciduous brush supplement the larger woody species listed above. In the short-grass subdivision mesquite is scarce or wanting and some of the other species are entirely lacking, being replaced by a few similar but more western forms. Juniper occurs in the Breaks.

In these last two subdivisions fires are infrequent and in some places never occur. As a result of this and of intensive grazing, the brush is invading many areas formerly in pure grass. Overgrazing has contributed somewhat to erosion, but the whole explanation does not lie here. The county agents within the region differ as to the probable effectiveness of tree planting in controlling erosion. The nature of the erosion, all of which takes place in the Breaks, has been described, and the prospect of controlling it will be discussed briefly later.

CRITICAL AREAS

Within the boundaries of the Red River drainage basin there are six distinct critical areas which exert a considerable influence on erosion and stream-flow control. These are: (1) the "Breaks" in northwestern Texas and southwestern Oklahoma, (2) the Wichita Mountains in southwestern Oklahoma, (3) the Arbuckle Mountains in south central Oklahoma, (4) the Ouachita Mountains in southwestern Arkansas and southeastern Oklahoma, (5) a portion of the

agricultural country in northeastern Texas, and (6) the hill region lying to the north and south of the Red River in north central Louisiana. These will be taken up in order.

1. *The Breaks.*—As implied by its name, this region marks the boundary or break between the high plains to the west and the lower rolling Red Prairie country to the east.

The Breaks extend back along the valleys which are being cut by the upper tributaries of the Red River throughout a considerable portion of northern Texas and southwestern Oklahoma. No maps showing the exact location of these Breaks in the Oklahoma region were available; therefore, this part of the critical area is not shown on the maps acompanying this report.

Soil erosion is extremely active along the Breaks, partly because the precipitation, although scanty in the aggregate, comes in sudden, hard rains, and partly because the slopes are steep and usually lack a vegetative cover. The surface of the High Plains beyond the eroded edges, as has been noted under Geology and Soils, apparently is unaffected by the erosion in the narrow canyons, and in many places the steepness of the escarpment between the Breaks and the High Plains is due to the cap rock, which underlies the High Plains and preserves their surface until it is undermined and broken off. The rain falling on the High Plains is almost entirely soaked up by the soil. The run-off, and consequently the erosion, occurs in the Breaks themselves. It is obvious that such erosion can be stopped only from below. The method of stopping it is a problem for research to solve. Several species of trees and shrubs, and many hardy grasses, grow in the region, but the task of establishing them where the extreme drought conditions prevail for long periods of time, and on bare slopes which disintegrate and wash away during the first rain, promises to be extremely difficult.

All of the seriously eroded areas which may in time be protected by vegetation, together with any less seriously threatened slopes now in grass or brush, should be protected from overgrazing and from the fires which still occasionally occur.

(2) The Wichita Mountains in southwestern Oklahoma and

(3) The Arbuckle Mountains in south central Oklahoma.

These isolated mountainous regions, occurring entirely within the State of Oklahoma, are critical from the standpoint of soil erosion chiefly because of their rugged topography. Because the greater portion of the Wichita Mountains is already under proper management in the Wichita National Forest and Fort Sill Military Reservation, the influence exerted by this area on stream control is considered beneficial. In the Arbuckle Mountains, however, rainfall is notably heavier than on the adjacent plains. Slopes that are cleared for cultivation erode so readily that clearings are soon abandoned. Although clearings are not abundant, they constitute an important and always a conspicuous part of the total area. On account of this excessive erosion, the influence of this region on stream flow and flood control is considered to be detrimental.

(4) The Ouachita Mountains portion of this drainage, adjoining areas where similar topographic and climatic conditions prevail, is but part of an extensive territory to the north and east of it. Considering its influence on soil erosion and regulation of run-off, practically all of this region of rugged topography should be kept in tim-

ber growth. A considerable part of the Oklahoma portion in this drainage is still in forest growth but because of the regularity with which fires have burned it in the past, its present condition is detrimental as regards erosion and run-off. More favorable conditions prevail in the portion of this drainage which lies in Arkansas, with the Ouachita National Forest covering part of it; hence that part has been classed as a neutral influence.

(5) Serious erosion has already taken place in the critical section of agricultural country in northeast Texas. This has come about through failure to use methods of cultivation, such as terracing or contour plowing, which would have prevented losses from excessive wash. Here the soils are more valuable for agriculture than for timber production, but each farm as a rule has its own wood lot. Many of the steeper slopes could well be kept in forest growth rather than under cultivation and, for those fields where excessive erosion has taken place, the planting or establishment of forest or grass cover is advisable. No recommendations are made for this critical area, which is classed as neutral in its effect, other than to stress the need for using such methods of cultivation as will assure a minimum of soil loss through washing.

(6) The hill region in northern Louisiana lying to the north and south of the Red River Valley shows evidences of excessive soil wash, especially where the original forests of longleaf pine have been entirely removed, and the whole area burned year after year. Its influence in flood control is decidedly detrimental.

The rating of the protective value of the entire Red River watershed has been put at 72.

RECOMMENDATIONS

The areas within this watershed which should be kept in forest cover are the Ouachita Mountains region in western Arkansas and southeastern Oklahoma and the hilly country of northern Louisiana which lies to either side of the Red River. This can best be brought about by public acquisition, in the form of national forests in the Ouachita Mountains and as either National or State forests or both, in Louisiana. This would extend fire protection to these areas, under which condition natural revegetation would surely ensue, because pines and hardwoods reproduce readily in most of this country if fires are kept out. Cutting practices must be regulated so as to leave a forest cover continuously on the ground. Some planting will be necessary in certain denuded parts of the longleaf country in northern Louisiana. The extension of the present boundaries of the Ouachita National Forest to include those parts of this watershed where similar topographic and climatic conditions prevail would place the critical area in the Ouachita Mountains region under Federal control and would assure its highest use from a soil conservation standpoint.

The Wichita Mountains are now largely under Government control. This control should extend to adjoining lands and to the Arbuckle Mountain region as well. In this way those lands could be made to afford a better regulation of the stream flow and better control of erosion than is obtained at present.

The Breaks present an erosion-control problem different from any other in this drainage basin. As noted above, the High Plains west of the Breaks suffer no erosion. The damage occurs in the Breaks themselves, and it is here that the soil must be fixed by a vegetative cover and possibly by engineering works. The particular difficulty in the Breaks is the result of climatic conditions; rainfall is deficient and drought prevails during much of the year. The precipitation comes in torrential downpours capable of washing out any scanty vegetation which may have survived the drought. The situation is serious and calls for energetic research on the part of all agencies, including the Forest Service, which have had experience in the revegetation of arid lands. Furthermore, investigations must be continued over a period sufficiently long to insure a trial of proposed methods under all possible extremes of climatic variations. Work should be started at once.

Some regulation of grazing may be necessary in the Breaks to preserve any protective vegetation that may be established.

APPENDIX II

ADDITIONAL AREA, CLIMATIC, AND SOIL DATA ON THE OHIO BASIN

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CLIMATE

The data on climate used in this report and in the reports on the tributaries of the Ohio were procured from Bulletin W, a publication of the Weather Bureau, United States Department of Agriculture. The records in this bulletin have been compiled for the most part only through the year 1920, with a few exceptions running on through 1921 and 1922. Hence the statement that the records cover a period varying from 4 to 102 years.

The records in Bulletin W give for each station the mean annual precipitation for the period of record. The range in precipitation over each watershed was found by taking the lowest and highest of the mean annual figures recorded at the stations in the watershed. Maximum precipitation represents the actual amount for the year which shows the highest record. The minimum, similarly, is the lowest precipitation for a year that was recorded in the drainage.

The range in mean annual depths of snow was procured by taking the lowest and highest from the records of the stations in the drainage. Special attention has been paid to areas where snowfall is excessive because in such sections the chances of damage from sudden thaws with subsequent voluminous run-off on frozen ground are materially increased. All temperature figures are means. The range in mean annual temperature was determined by taking the lowest, and the highest mean records for each station in the watershed.

The following quotation on floods on the Ohio was abstracted from the Report on Mississippi Floods, by Humphreys and Abbott.

> The first rise occurs when the snow melts and winter breaks up. Generally, this occurs in February, but is sometimes later. This rise is usually the highest for the year. The next rise occurs in May or June. The period of low water is usually from August to October when the fall rains cause it to begin its rise.

Floods, Ohio River

	Pool below falls	On rapids at head of falls
Height above low water at Louisville, Ky.:	*Feet*	*Feet*
Feb. 22, 1832	64	42
Dec. 20, 1847	63.2	41.2
April—		
1851 (double rise)		33.5
1854		34
1859		32

COMPARATIVE DATA

The following table gives the amount of surface evaporation in inches and the precipitation in inches for identical periods.

CLARKSBURG, W. VA.

[Dates are inclusive]

Year	Interval over which evaporation records were kept	Precipitation for the period	Evaporation for the period
		Inches	*Inches*
1923	June–December	26.06	24.392
1924	March–October	35.56	33.331
1925	do	30.45	35.754
1926	April–October	33.43	30.858
1927	do	27.00	30.065

WOOSTER, OHIO

Year	Interval over which evaporation records were kept	Precipitation for the period	Evaporation for the period
1921	April–October	23.17	31.937
1922	do	21.81	31.465
1923	do	19.62	29.728
1924	do	25.73	26.933
1925	June–October	15.30	20.890
1926	May–October	25.25	20.549
1927	do	18.56	20.256

OHIO STATE UNIVERSITY, COLUMBUS, OHIO

Year	Interval over which evaporation records were kept	Precipitation for the period	Evaporation for the period
1921	April–October	19.50	33.300
1922	May–October	16.87	27.556
1923	April–October	23.75	29.682
1924	do	19.10	28.526
1925	June–October	13.23	23.298
1926	May–October	23.25	25.388
1927	April–October	22.92	25.953

WATER POWER

The following tables were furnished by Lasley Lee, district engineer, United States Geological Survey, Columbus, Ohio.

Report on developed water power in Indiana, 1927

[Developments of 100 horsepower or more]

Location	Town	Capacity
		Horsepower
Tippecanoe River	Norway	9,825
East Fork White River	Williams	4,460
West Fork White River	Noblesville	600
Whitewater Canal	Connersville	380
Do	do	620
Do	do	190
Do	do	310
Do	do	210
West Fork Whitewater River	Brookville	250
Tippecanoe River	Oakdale	14,550
Total		31,395

Report on developed water power in Ohio, 1927

[Developments of 100 horsepower or more]

Location	Town	Capacity
		Horsepower
West Fork Mahoning River	Newton Falls	766
East Fork Mahoning River	do	973
Mahoning River	Leavittsburg	510
Tuscarawas River	Zoar	170
Do	New Philadelphia	350
Walhonding River	Roscoe	1,600
Muskingum River	Zanesville	147
Do	do	1,070
Do	McConnelsville	175
Do	Malta	250
Little Miami River	Morrow	160
Greenville Creek	Covington	790
Stillwater River	West Milton	234
Miami River	Middletown	817
Do	Hamilton	3,000
Total		11,014

The following letter relative to water-power development in North Carolina has been copied from the files of the State forester.

State of North Carolina,
Department of Conservation and Development,
Chapel Hill.

Dear Mr. Holmes: With further reference to my recent letter regarding the storage of various projects of the Tallassee Power Co., on the Little Tennessee River and its tributaries in North Carolina, I beg to state that the following information has been furnished from the headquarters office, Aluminum Co. of America, at Pittsburgh.

The present development at Cheoah uses now 730,000,000 cubic feet but after the completion of the Santeetlah project now under construction this figure will be reduced to 300,000,000 cubic feet. The Santeetlah project which is now under construction on the Cheoah River immediately above the North Carolina-Tennessee State line and which will be placed in operation about January 1 of next year, will have 5,600,000,000 cubic feet. This storage will be really effective for flood-control purposes.

The Calderwood project on the Little Tennessee River in Tennessee immediately below the present Cheoah development which has just begun construction will have when completed 300,000,000 cubic feet storage.

Of the three projects now completed or under construction on the Little Tennessee and its tributaries only the Santeetlah project has or will have sufficient storage to be of any marked benefit for flood-control purposes. The amount of storage stated, however, 5,000,000,000 cubic feet will not be sufficient to completely regulate the Little Tennessee River for flood-control purposes. When additional projects of the Tallassee Power Co. on the upper Little Tennessee River are completed, the river will undoubtedly be completely regulated.

Yours very truly,

Thorndike Saville,
Chief Hydraulic Engineer.

P. S.—The Pigeon River Power Co., a subsidiary of the Carolina Power & Light Co. has under construction on the Big Pigeon River near Waterville, N. C., just northeast of the Carolina-Tennessee boundary line, a power plant, which calls for 85,000 installed horsepower. The reservoir in connection with this plant is located on the Pigeon River between Fines Creek and Jonathan Creek. The capacity of this reservoir is only 17,400,000 cubic feet. It will be completed the latter part of 1928.

There are reservoir sites on the Hiwassee River and the Little Tennessee River which are controlled by power companies and which are susceptible of completely regulating these streams, but no immediate construction is under consideration.

T. S.

Development of Water Power

Federal Power Commission,
Washington, September 16, 1927.

Dear Colonel Greeley: With reference to your letter of September 7 (F, special-flood control) requesting estimates on the development of water power in the Ohio River basin:

There is shown in the following table the estimated capacity in horsepower of water wheels installed in plants in the Ohio River drainage basin having a capacity of 100 horsepower or more at the close of the years indicated:

Year	Horsepower	Year	Horsepower
1909	48, 900	1918	217, 400
1910	49, 700	1919	290, 500
1911	53, 700	1920	291, 600
1912	121, 000	1921	292, 600
1913	157, 800	1922	292, 800
1914	178, 200	1923	294, 600
1915	202, 900	1924	346, 600
1916	215, 600	1925	685, 000
1917	216, 300	1926	757, 000

These estimates were obtained by Mr. Davenport from the data compiled in connection with the preparation of the diagram shown in the circular of January 1, 1927, issued jointly by the Geological Survey and the commission. These data were obtained in considerable part from the records of the Geological Survey of water-power plants in the United States having a capacity of 100 horsepower or more.

It is interesting to note that of the 708,100 horsepower developed in the Ohio River Basin from 1910 to 1926, inclusive, 475,000 horsepower, or 67 per cent, was on the Tennessee River and its tributaries. The capacity of 261,400 horsepower accredited to the Muscle Shoals plant on the Tennessee River, comprises 37 per cent of the total development from 1910 to 1926, this plant having commenced operation in 1925.

The table shows that development increased considerably from 1911 to 1916 and then, due probably to economic conditions arising from the war, was halted for several years, except in the year 1919, when the Cheoah plant of Knoxville company went into operation. In 1924, 1925, and 1926 there were large increases in development.

Very truly yours,

O. C. Merrill,
Executive Secretary.

The following statement is made by Tennessee Geological Survey:

Installations proposed at projects for which applications have been made for preliminary permits or licenses

	Horsepower
Sites on Tennessee River:	
Interstate	260, 000
Sherman	44, 000
Soddy	60, 000
White Creek	100, 000
Marble Bluff	44, 000
Coulter Shoals	47, 000
Sites on Clinch River:	
Kingston	36, 000
Melton Hill	54, 500
Clinton	30, 500
Cove Creek	100, 000
War Ridge	50, 000
Cumberland Gap site on Powell River	26, 500
Sites on Hiwassee River:	
Apalachia	150, 000
Cromley	100, 000

	Horsepower
Sites on Holston River:	
No. 1	$24, 000
No. 2	30, 000
No. 3	20, 000
Cataloochia site on Big Pigeon River	67, 000
The Tennessee Eastern Electric Co. has applied for 3 sites on the Nolichucky River, to have a total capacity of	70, 000
Installation at Muscle Shoals No. 3 site, as proposed by United States Army Engineers	165, 000
Installation justified at Guntersville, as stated in partial report contained in House Document No. 463, Sixty-ninth Congress, first session	160, 000

Sites Nos. 1 to 7 on Nolichucky River, not stated in application.
Site on Emery River, capacity not given.

For installations at sites on Tennessee, Clinch, Powell, Hiwassee, and Big Pigeon Rivers, as recommended by this office under date of May 22, 1926, see page 15, House Document 463, Sixty-ninth Congress, first session.

TABLE 1.—*Areas of tributaries of the Ohio River Basin*

[Square miles]

Tributaries	Alabama	Georgia	Illinois	Indiana	Kentucky	Maryland	Mississippi	New York	North Carolina	Ohio	Pennsylvania	Tennessee	Virginia	West Virginia	All States
Allegheny								1, 929			9, 754				11, 683
Beaver										1, 370	1, 812				3, 182
Big Sandy					2, 239								996	1, 024	4, 259
Cumberland					7, 116							10, 823			17, 939
Green					8, 948							381			9, 329
Guyandot and Twelve Pole														2, 354	2, 354
Kanawha									734				3, 127	8, 442	12, 303
Kentucky					6, 945										6, 945
Licking					3, 742										3, 742
Little Kanawha														2, 382	2, 382
Miami				1, 427						3, 925					5, 352
Monogahela						407					2, 718			4, 214	7, 339
Muskingum										8, 052					8, 052
Ohio River (direct)			2, 865	4, 164	6, 341					9. 322	1, 258			2, 289	26, 239
Salt					2, 986										2, 986
Scioto										6, 361					6, 361
Tennessee	6, 739	1, 469			994		421		5, 392			22, 267	3, 141		40, 423
Clinch												2, 494	1, 784		4, 278
French Broad									2, 797			2, 255			5, 052
Hiwassee		847							616			1, 239			2, 702
Holston									199			2, 270	1, 357		3, 826
Little Tennessee		43							1, 780			726			2, 549
Tennessee (direct)	6, 739	579			994		421					13, 283			22, 016
Wabash			8, 600	24, 080						232					32, 912
Ohio River Basin	6, 739	1, 469	11, 465	29, 671	39, 311	407	421	1, 929	6, 126	29, 262	15, 542	33, 471	7, 264	20, 705	203, 782

TABLE 2.—*Estimated area of lands in farms, crops, pasture, and forest—Ohio Basin—by drainage areas* [1]

Tributary	Total area in the drainage [2]	Portion of the area in farms	Farm land				Farm woodland pastured	Total wooded area [4]
			Total area [3]	Crop land	Pasture	Woodland		
	Square miles	*Per cent*	*Square miles*	*Square miles*	*Square miles*	*Square miles*	*Square miles*	*Square miles*
Allegheny	11, 683	65. 0	7, 590	3, 015	2, 580	1, 570	920	4, 920
Beaver	3, 182	73. 3	2, 325	1, 155	915	362	269	584
Big Sandy	4, 259	57. 3	2, 440	515	857	945	214	1, 660
Cumberland	17, 939	69. 1	12, 400	4, 650	3, 585	3, 940	1, 063	7, 975
Green	9, 329	81. 4	7, 590	3, 015	2, 462	1, 645	378	2, 650
Guyandot-Twelvepole	2, 354	52. 2	1, 230	296	421	537	127	1, 470
Kanawha	12, 303	58. 0	7, 140	1, 475	3, 320	2, 582	645	7, 010
Kentucky	6, 945	74. 8	5, 195	1, 455	2, 490	1, 040	364	2, 700
Licking	3, 742	82. 8	3, 100	776	1, 740	703	239	1, 071
Little Kanawha	2, 382	77. 4	1, 845	348	987	580	133	895
Miami	5, 352	81. 8	4, 830	3, 010	1, 430	483	388	483
Monongahela	7, 339	64. 0	4, 700	1, 370	1, 895	1, 165	463	2, 955
Muskingum	8, 052	88. 5	7, 130	3, 080	3, 160	924	525	1, 215
Ohio (direct)	26, 239	81. 7	21, 450	8, 800	8, 750	3, 780	1, 640	5, 810
Salt	2, 986	82. 9	2, 475	735	1, 296	354	124	708
Scioto	6, 361	85. 8	5, 460	2, 890	1, 930	714	378	952
Clinch	4, 278	57. 6	2, 465	638	980	810	138	2, 380
French Broad	5, 052	61. 4	3, 100	1, 020	1, 220	1, 220	366	2, 620
Hiwassee	2, 702	62. 5	1, 690	519	328	845	127	1, 880
Holston	3, 826	68. 0	2, 600	759	1, 010	866	147	1, 695
Little Tennessee	2, 549	60. 0	1, 174	313	339	548	137	1, 850
Tennessee (direct)	22, 016	61. 8	13, 600	5, 920	3, 075	4, 620	1, 109	11, 850
Wabash	32, 912	84. 8	27, 900	17, 700	5, 590	2, 890	1, 580	2, 890
Total for basin	203, 782	--------	149, 429	63, 454	50, 360	33, 123	11, 474	68, 223
Total expressed in per cent	100. 0	--------	73. 3	31. 1	24. 7	16. 3	[5] 5. 6	33. 5

[1] Compiled from U. S. Census of Agriculture, 1925.
[2] Areas planimetered on State bases and adjusted to surveyed area of each State.
[3] This total is not the sum of the following columns because uses of land for pasture and woodland areas overlap.
[4] Includes all farm woods and all wild land unclassified outside of farms after deducting for cities, villages, roads, and other improvements.
[5] 34.6 per cent of total woodland on farms.

TABLE 3.—*Protective value of the watersheds in the Ohio Basin with regard to precipitation, taking into account both the amount of precipitation and its distribution*

Drainage area	General average of precipitation	Distribution of precipitation	Character of distribution	Scale rating [1]
	Inches	*Per cent of area*		
Allegheny	42.5	50 50	Medium Poor	71
Beaver	38.0	90 10	Good Medium	90
Big Sandy	42.5	100	Poor	66
Clinch	51.0	100	do	62
Cumberland	48.5	50 50	Medium Poor	69
French Broad	47.5	100	do	64
Green	47.5	100	Medium	76
Guyandot	47.5	50 50	do Poor	70
Hiwassee	58.0	100	do	59
Holston	45.0	100	do	66
Kanawha	41.5	100	do	65
Kentucky	45.0	50 50	Medium Poor	70
Licking	43.7	50 50	Medium Poor	71
Little Kanawha	42.5	100	do	66
Little Tennessee	59.0	100	do	58
Miami	37.5	50 50	Good Medium	86
Monongahela	46.2	100	Poor	65
Muskingum	39.7	100	Good	91
Ohio (direct)	42.5	60 20 20	do Medium Poor	83
Salt	43.5	100	Medium	79
Scioto	37.5	100	Good	92
Tennessee (direct)	51.0	25 75	Medium Poor	66
Wabash	39.0	100	Good	91

[1] The scale rating represents the protective value. It was determined by giving a precipitation of 20 inches and below with good distribution a rating of 100, and a precipitation of 80 inches and above with poor distribution a rating of 50.

Protective value ratings for the general soil provinces within individual drainage areas of the Ohio River basin

	Upper glaciated province		Appalachian Plateau excepting Permian and late Pennsylvanian	Limestone areas of eastern West Virginia	Limestone uplands		Appalachian Valley	Driftless areas of Indiana	Unaka Mountains and Blue Ridge Mountains	Permian and late Pennsylvanian		Alluvium loess, Illinois drift	Cretaceous of western Tennessee	Erosion rating for individual drainage areas
	Glacial limestone soils	Glacial sandstone shale soils			Upper Mississippian	Lower Mississippian				Dunkard formation	Monongahela formation			
Erosion ratings	90	90	80	80	70	70	70	70	60	60	60	50	50	
Allegheny:														
Square miles		3,861	7,727								95			83
Per cent		33	66								1			
Beaver:														
Square miles		2,311	871											87
Per cent		73	27											
Big Sandy:														
Square miles			4,134				35			90				79
Per cent			97				1			2				
Cumberland:														
Square miles			5,339		9,797	2,646						157		73
Per cent			30		54	15						1		
Green:														
Square miles			2,799		3,255	2,529						746		71
Per cent			30		35	27						8		
Guyandot:														
Square miles			1,483							871				73
Per cent			63							37				
Kanawha:														
Square miles			4,826	2,584			2,179		1,508	1,206				74
Per cent			39	21			18		12	10				
Kentucky:														
Square miles			3,638		2,890	244						173		75
Per cent			52.5		41.5	3.5						2.5		
Licking:														
Square miles			758		2,755	199						30		72
Per cent			20		74	5						1		
Little Kanawha:														
Square miles			598							1,784				65
Per cent			25							75				
Miami:														
Square miles	4,915											437		87
Per cent	92											8		
Monongahela:														
Square miles			3,789	1,450						996	1,104			75
Per cent			51	20						14	15			

Muskingum:														
Square miles		3,687	3,250							360	755			82
Per cent		46	40.5							4.5	9			
Ohio River (direct):														
Square miles	961	351	4,198		1,516	583				5,072	1,488	12,070		61
Per cent	4	1	16		6	2				19	6	46		
Salt:														
Square miles					2,347	307						332		68
Per cent					78.5	10.5						11		
Scioto:														
Square miles	4,158	876	376		110	691						150		86
Per cent	65.5	13.5	6		1.5	11						2.5		
Clinch:														
Square miles			1,674				2,604							74
Per cent			39				61							
French Broad:														
Square miles							1,675		3,377					63
Per cent							33		67					
Hiwassee:														
Square miles							894		1,808					63
Per cent							33		67					
Holston:														
Square miles							2,878		948					68
Per cent							75		25					
Little Tennessee:														
Square miles							395		2,154					62
Per cent							15.5		84.5					
Tennessee (direct):														
Square miles			5,148		7,456	3,540	2,172		94			823	2,783	69
Per cent			23		34	16	10		0.5			4	12.5	
Wabash:														
Square miles	14,215	4,466						1,989				12,242		74
Per cent	43	14						6				37		
Ohio Basin	24,249	15,552	50,608	4,034	30,126	10,739	12,832	1,989	9,889	10,379	3,442	27,160	2,783	72
Entire	12	8	25	2	15	5	6	1	5	5	2	13	1	

APPENDIX III

ADDITIONAL DATA ON FLOODS AND RUN-OFF ON MONONGAHELA AND ALLEGHENY DRAINAGES

E. F. McCarthy, *Central States Forest Experiment Station*

RUN-OFF AND FLOOD HISTORY [1]

Flood records at Pittsburgh for the past 30 years

[Flood stage, 22 feet]

Date	Height of flood	Stream causing flood	Date	Height of flood	Stream causing flood
	Feet			*Feet*	
Feb. 24, 1897	29.5	Monongahela.	Jan. 15, 1911	23.8	Allegheny.
Mar. 24, 1898	28.9	Allegheny.	Jan. 31, 1911	25.2	Do.
Mar. 6, 1899	22.0	Monongahela and Allegheny.	Mar. 22, 1912	28.1	Monongahela and Allegheny.
Nov. 27, 1900	27.7	Do.	Jan. 9, 1913	31.3	Do.
Apr. 7, 1901	22.1	Do.	Jan. 12, 1913	26.3	Allegheny.
Apr. 21, 1901	27.5	Do.	Mar. 28, 1913	30.4	Monongahela and Allegheny.
Dec. 16, 1901	25.8	Do.			
Mar. 1, 1902	32.4	Do.	Nov. 17, 1913	22.2	Do.
Feb. 5, 1903	24.0	Do.	Feb. 3, 1915	28.4	Do.
Mar. 1, 1903	28.9	Do.	Dec. 19, 1915	22.6	Allegheny.
Jan. 23, 1904	30.0	Allegheny.	Jan. 23, 1917	25.2	Monongahela and Allegheny.
Mar. 4, 1904	26.9	Do.			
Mar. 8, 1904	23.2	Do.	Mar. 13, 1917	23.1	Allegheny.
Mar. 22, 1905	29.0	Do.	Jan. 21, 1918	27.1	Monongahela.
Dec. 4, 1905	23.5	Do.	Mar. 15, 1918	25.9	Allegheny.
Jan. 20, 1907	23.3	Monongahela and Allegheny.	Jan. 3, 1919	22.9	Monongahela and Allegheny.
Mar. 15, 1907	35.5	Do.	Mar. 13, 1920	25.1	Do.
Mar. 20, 1907	22.4	Do.	Nov. 29, 1921	25.4	Allegheny.
Feb. 16, 1908	30.7	Do.	Jan. 4, 1924	27.4	Do.
Mar. 20, 1908	27.3	Allegheny.	Mar. 30, 1924	29.2	Monongahela and Allegheny.
Feb. 25, 1909	22.3	Do.			
May 1, 1909	22.2	Do.	May 13, 1924	26.4	Do.
Jan. 19, 1910	22.8	Monongahela and Allegheny.	1925	----------	None.
			1926	----------	Do.
May 1, 1910	22.0	Allegheny.			

[1] Taken in part from Table 11, p. 44, Report of Pittsburgh Flood Commission.

The above table is taken from the Weather Bureau records at Pittsburgh. The flood stage at this station is 22 feet and the gauge is located in the Monongahela just above the confluence of the Monongahela and the Allegheny. Floods at Pittsburgh may be caused by either or both rivers. The Allegheny drainage area is greater than the Monongahela but the Allegheny flood waters are collected more rapidly and move to Pittsburgh more swiftly. The crest of the Monongahela flood usually reaches Pittsburgh after the Allegheny peak and tends to prolong the high stage but rarely causes the maximum.

The Allegheny is the critical river of the two, as far as floods at Pittsburgh are concerned. The greatest flood of the Monongahela,

July 11, 1888, was accompanied by no rise in the Allegheny, and the stage was only 22 feet.

During the 1907 flood at Pittsburgh, which was the greatest since the establishment of the weather bureau there, and which owed its severity to the synchronizing of the flood stages of the two rivers, the Monongahela was very high while the Allegheny, although in flood, was below the maximum. Had the Allegheny been at a record height, a much more serious flood would have resulted.

The importance of synchronized floods is further emphasized by the relative position of the Kiskiminetas and Youghiogheny Rivers in the drainage area. The Kiskiminetas is the largest tributary of the Allegheny and the Youghiogheny is the largest branch of the Monongahela. Both enter the main river from the east and at comparatively short distances above Pittsburgh. The drainages of the two rivers lie adjacent at the headwaters, consequently weather conditions are more or less uniform. Therefore, a flood in one of these rivers is usually accompanied by high water in the other. The crests of the two floods reach Pittsburgh about the same time—hence these rivers have been contributors to every great flood recorded at Pittsburgh. Records further show that one river or the other or both have been solely responsible for minor floods at Pittsburgh.

Contributing causes of floods in the Allegheny and Monongahela Rivers already have been stated in general under "Climate." The following tables indicate relationship of run-off and precipitation:

Rainfall and run-off on portions of the Allegheny River watershed [1]

Station	Year	Average rainfall on drainage basin	Run-off	Ratio of run-off to precipitation
		Inches	*Inches*	*Per cent*
Allegheny River at Aspinwall; drainage area, 11,580 square miles	1903	43.77	31.24	71.4
Do	1904	41.84	33.16	79.2
Do	1905	45.42	23.72	52.2
Do	1906	39.23	26.68	68.0
Do	1907	43.04	26.39	61.2
Mean		42.66	28.24	66.4
Allegheny River at Kittanning, Pa.; drainage area, 9,010 square miles	1906	41.90	21.10	50.4
Do	1907	41.94	25.90	61.7
Do	1908	36.95	26.70	72.4
Do	1909	39.69	23.10	63.0
Do	1910	39.99	22.40	57.0
Mean		40.09	23.84	60.6

[1] Data taken from Report of Pittsburgh Flood Commission; appendix, p. 315, Table 49.

Records of run-off by months are available at Kittanning, Pa., for 19 years. These records are averaged below. The mean is very close to the mean for the 5-year period given above. The mean precipitation has not been determined for the 19-year period, but the run-off is probably about 60 per cent of the precipitation.

Average run-off, in inches of precipitation, 1904–1923, inclusive [1]

[Basin of the Allegheny River above Kittanning, Pa.]

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Average run-off	3.18	2.16	4.54	2.85	2.38	1.25	0.78	0.49	0.62	1.11	1.70	1.95	23.01
Per cent of total run-off	13.8	9.4	19.7	12.4	10.4	5.4	3.4	2.1	2.7	4.8	7.4	8.5	100.0
Per cent of total run-off by seasons	42.9			28.2			8.2			20.7			
Basis: Years of record (number of years)	18	17	17	18	17	19	19	19	19	19	19	18	------

[1] Data taken from report of Pittsburgh Flood Commission, appendix, pp. 95–96, and from records of the U. S. Weather Bureau at Pittsburgh, Pa.

The occurrence of floods, by months, at Pittsburgh, Pa.[1]

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Number of floods, 1904–1923	10	4	13	0	2	0	0	0	0	0	2	2

[1] Compiled from data in report of the Pittsburgh Flood Commission.

From the above tables it is seen that 63.6 per cent of the run-off occurs in the six winter months, October to March, inclusive, 42.9 per cent occurring in January, February, and March, the three months for which the greatest number of floods occur.

The history of no two individual floods is the same. Weather conditions vary greatly, and the areas contributing the greatest amount of flood water are never the same. As to the contributing causes of floods for the Allegheny and Monongahela Basins as a whole, the general statement under "Climate" will suffice.

The table of flood frequency accompanying the run-off table indicates the relationship of run-off and floods. No floods were recorded at Pittsburgh for April, although the percentage of run-off was in excess of that for May, December, and November. This emphasizes the importance of synchronism in floods. It indicates that the Monongahela River was not in flood in April in time to unite its flood waters with those of the Allegheny.

Frequency of floods at Pittsburgh is shown in the table at top of page 701. This shows the frequency to have increased until the 1906–1910 period. The number now seems to be on the decrease.

Frequency of floods at Pittsburgh, Pa., by periods [1]

[1871–1925, inclusive]

	Number of floods				Total
Height of flood crests in feet	22–26	26–30	30–35	35–40	
5-year period:					
1871–1875	2	0	0	0	2
1876–1880	3	0	0	0	3
1881–1885	3	2	1	0	6
1886–1890	7	1	0	0	8
1891–1895	6	0	1	0	7
1896–1900	2	3	0	0	5
1901–1905	5	4	2	0	11
1906–1910	8	1	1	1	11
1911–1915	4	3	2	0	9
1916–1920	5	1	0	0	6
1921–1925	1	3	0	0	4
Total	46	18	7	1	72

[1] 1871–1910 compiled from data in the report of the Pittsburgh Flood Commission; 1910–1927 compiled from records of the U. S. Weather Bureau at Pittsburgh.

Restriction of the natural stream channels has been the cause of increased flood heights at Pittsburgh and other points along the rivers and tributaries. Retaining walls, bridge piers and abutments, railroad fills, etc., have all tended to restrict the original channel.

During ordinary stages neither the Monongahela nor Allegheny carry much sediment. There is usually some difference in the color of the two rivers at their confluence, but this is due to the greater amount of mine and mill drainage in the Monongahela. The tributaries of both rivers are clear, even those coming from burned and cut-over land. During flood periods both rivers carry much silt. The writer has seen 3 inches of silt deposited by flood waters of the Allegheny. This, however, was deposited from water which remained on the land for several weeks. One-half inch from a single flood, however, is not uncommon.

Gravel bars above the slack-watered areas are common, but are usually the outwash from tributary streams. At the mouth of all tributary streams there are alluvial fans of gravel and sand.

Average run-off in inches of precipitation, by seasons

[Basin of the Monongahela River above Hoult, W. Va., 1917–1924, inclusive]

	Winter (January, February, March)	Spring (April, May, June)	Summer (July, August, September)	Fall (October, November, December)	Total
Average run-off	11.90	6.14	1.96	5.34	25.34
Per cent of total run-off, by seasons	47.0	24.2	7.7	21.1	100.0

Per cent of total run-off, October to March, inclusive	68.1
Per cent of total run-off, April to September, inclusive	31.9
Total	100.0

The above record would indicate in general that the seasonal run-off for the Monongahela is about the same as that for the Allegheny. The relative position of the station at Hoult is not the same, however, as the station at Kittanning in the Allegheny watershed, considering

that the drainage at Kittanning is from 77 per cent of the entire Allegheny watershed, while that at Hoult is from only 34 per cent of the Monongahela watershed.

The maximum stage recorded in the Monongahela River, independent of the Allegheny flood waters, was July 11, 1888. Unfortunately, precipitation records preceding this flood are meager, but it must have been the result of extremely heavy and concentrated precipitation. Normally, run-off in July is not great and the precipitation for June, 1888, was below normal at all stations of record, so that the ground could not have been saturated preceding the July rains.

The flood of March 15, 1907, in the Monongahela River was only exceeded by the 1888 flood. This flood was the result of a combination of unusually high temperatures, melting snow, and heavy rainfall. The entire Monongahela watershed received for the 48-hour period preceding 8 a. m., March 15, 1907, 1 to 4 inches of rainfall. In addition to this, temperatures were high and there was 2 to 8 inches of wet snow on the ground.

Average run-off in inches of precipitation, by months, Monongahela River proper,[1] 1917–1924, inclusive

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Average run-off	4.13	3.35	4.42	2.16	2.83	1.15	0.89	0.59	0.48	0.66	1.65	3.03	25.34

[1] These are the only run-off records available on the Monongahela River proper. The area drained i 2,430 square miles. Data on relationship of run-off and precipitation for the Monongahela watershed ar not as complete as for the Allegheny. Gauging stations have been maintained only on tributaries of th e Monongahela River.

Precipitation and run-off on tributaries of Monongahela River

Station	Period	Total precipitation	Total run-off	Per cent of precipitation in run-off
		Inches	*Inches*	*Per cent*
Deckers Creek, Morgantown, W. Va.	October, 1912, to September, 1915, inclusive.	111.90	93.57	83.6
Cheat River, Parsons, W. Va.[1]	January, 1913, to September, 1920, inclusive.	102.56	74.97	73.1
Do	October, 1918, to September, 1920, inclusive.	87.92	66.96	76.2
Shavers Fork, Parsons, W. Va.[2]	October, 1910, to September, 1915, inclusive.	264.96	211.05	79.6
Do	October, 1916, to September, 1920, inclusive.	169.15	156.61	92.5

[1] April and May, 1913; April, May, and June, 1914, omitted.
[2] January and February, 1914, omitted.

The summer of 1908 was exceedingly dry throughout the Allegheny drainage basin. To demonstrate the effect of forest cover on conservation of water and its release during periods of drought, figures have been compared. The effect of glacial till soils and glaciated topography has also been included.

Comparison of discharge during drought from forested, deforested, and glaciated stream basins (portions of the Allegheny drainage)[1]

Stream	Date	Discharge of stream	Drainage area at point of measurement	Discharge
		Cubic feet per second	*Square mile*	*Cubic feet per square mile*
Deforested basins:				
Kiskiminetas River	Sept. 25, 1908	68.4	1,683	0.04
Black Lick Creek	Sept. 24, 1908	6.6	403	.016
Loyalhanna Creek	do	10.7	300	.036
Forested basins:				
Tionesta Creek	Sept. 28, 1908	39.7	455	.09
Brokenstraw Creek	do	45.2	300	.15
Glaciated areas:				
Partly forested basins—				
Brokenstraw Creek	do	45.2	300	.15
Oil Creek	Sept. 27, 1908	39.3	305	.13
Deforested basins—				
French Creek	do	64.0	896	.07
Shenango River	Sept. 23, 1908	29.0	765	.04
Neshannock Creek	do	41.3	245	.17

[1] Data from Pennsylvania Water Supply Commission Report, 1908, pp. 61–62, Tables 25, 26, and 27.

Forest areas, Monongahela drainage, by cover types and percentage of land having forest

	Percentage of area having forest					Total
Cover type	10	11–25	26–50	51–75	76–100	
Area in square miles:						
Spruce				31	389	420
Upland hardwoods	93	363	500	733	491	2,180
Nonwooded	1,771	1,655	814	432	67	4,739
Total	1,864	2,018	1,314	1,196	947	7,339

Forest areas, Allegheny drainage, by cover types and percentage of land having forest

	Percentage of area having forest					Total
Cover type	10	11–25	26–50	51–75	76–100	
Area in square miles:						
Upland hardwoods	10	537	1,570	1,995	1,047	5,159
Nonwooded	188	2,454	2,566	1,171	145	6,524
Total	198	2,991	4,136	3,166	1,192	11,683

APPENDIX IV

INFLUENCE OF FOREST COVER UPON LOAD OF SUSPENDED MATTER CARRIED BY STREAMS IN FLOOD STAGE

C. F. Korstian, *Appalachian Forest Experiment Station*

In order to get a quantitative expression of the relative amounts of suspended matter carried by flooded streams draining cleared and forested lands, samples of water were collected from the French Broad River at Long Shoals Bridge above Asheville, and above Rosman, from Hominy Creek near West Asheville, from Dillingham Creek below Dillingham, N. C., and from a tributary of Big Ivy, during the flood of August 16–18, 1928. All these streams were in flood stage when the samples were collected. The following tabulation gives the results of the comparison:

Name of stream and approximate location	Date of sampling	Approximate percentage of forest land on watershed above point of sampling	Amount of suspended matter in parts per million [1]	Kind of suspended matter
		Per cent		
French Broad River above Rosman, N. C.	Aug. 17, 1928	90–95	11	Mostly particles of organic matter, some fine sand.
French Broad River at Long Shoals Bridge.	-----do--------	40–45	107	Organic matter, fine sand, silt, and clay.
Dillingham Creek 1½ miles below Dillingham, N. C.	Aug. 18, 1928	95	4	Mostly particles of organic matter, some fine sand.
——— Creek one-half mile below Democrat, N. C.	-----do--------	[2] 10–15	4, 370	Mostly clay and silt, some fine sand, very little organic matter.
Hominy Creek at Brevard Road Bridge near West Asheville, N. C.	-----do--------	30–35	3, 405	Mostly sand, some silt, little organic matter.

[1] Determined on basis of dry weight of suspended matter per weight of given volume of water.
[2] Much land cultivated.

The heavy rainstorm of August 15 and 16, which resulted in a 12-foot flood stage in the French Broad River at Asheville, began about 5 a. m., August 15, and ended at 1 a. m., August 16, giving a total rainfall of 4.45 inches for the storm. The rainfall records for Asheville for the first 19 days of August, 1928, are as follows:

	Inches		Inches
Aug. 1	0	Aug. 11	0. 33
Aug. 2	0	Aug. 12	1. 33
Aug. 3	Trace.	Aug. 13	Trace.
Aug. 4	0. 27	Aug. 14	0. 07
Aug. 5	0. 89	Aug. 15	4. 42
Aug. 6	0. 07	Aug. 16	0. 03
Aug. 7	0	Aug. 17	Trace.
Aug. 8	Trace.	Aug. 18	Trace.
Aug. 9	0. 31	Aug. 19	0. 04
Aug. 10	0. 20		

From the above precipitation records it is evident that the soil and the litter of the forest floor had been well saturated during the rainy period of August 4 to 12, on the last two days of which over 1½ inches of rain fell.

The suspended matter contained in the water of forest streams consists chiefly of particles of organic matter such as minute pieces of leaves, partly rotted wood, etc., and a small amount of fine sand, while that contained in the water of streams draining cleared land is mostly clay, much of which is colloidal and will remain in suspension indefinitely and is capable of being carried long distances, with some silt and sand but very little organic matter.

APPENDIX V

TENNESSEE IN FLOOD CONTROL OF THE MISSISSIPPI DRAINAGE

R. S. Maddox, *State Forester of Tennessee*

Tennessee as a drainage area lies almost wholly within the Mississippi watershed. Only a very few square miles, chiefly on the southeastern border of the State, drain into the Gulf of Mexico. Tennessee may be said to have three main watersheds, viz, the Tennessee River, the Cumberland River, and drainage directly into the Mississippi River.

The Tennessee River flows through the East Tennessee Valley, which has an average width of 50 miles. The river also drains both the Smoky Mountains on its east and the Cumberland Mountains on its west, embracing in all a watershed area of about 13,700 square miles in the eastern section of the State. The larger forested areas in this portion of its drainage area lie in the Smoky Mountains and the Cumberland Plateau. The forested lands of the East Tennessee Valley proper are largely in farm woodlands. No large area in the Smoky Mountains has been cleared for farm use, and a big portion of what has been cleared should still be in forest. For the most part cleared lands display a neglected condition as evidenced by sheet erosion, gullies, or soil depletion. Many cleared areas are on shallow soil, and others are on exceedingly steep slopes where it is practically impossible to maintain them in proper condition for tillage or suitable pasture. Numerous tracts, however, once cleared, cultivated, and abandoned, have reverted to tree growth by natural seeding. This is particularly true where natural seeding has not been interrupted by grazing.

The East Tennessee Valley is composed of hilly, rolling, and level areas, and contains extensive farm land, much of which is too shallow of soil and too steep to cultivate. Here as elsewhere an abundance of land available for clearing has enabled the owners to wear out the soil followed by clearing of new ground. It follows that a considerable percentage of this area is now lying out, in part gullied, in part so badly depleted of fertility that it is useless to consider it further for crop production. At present it is reverting to tree growth from natural seeding where grazing has not interfered.

The East Tennessee section of the Cumberland Plateau drains directly into the Tennessee River. It is dissected by deep, steep, rocky gulches whose drainage systems are generally covered with forests. Portions of the plateau proper are quite level, or rolling, and contain the major areas of the forest lands. The soil is usually sandy or gravelly. These forested lands, however, have been

logged to a great extent and burned over periodically. The removal of the timber has been done, as a rule, with no provision for protection against fires or to insure stands of young trees.

Practically none of these mountain lands can be said to be devoid of forest cover, except these which have been cleared for cultivation. Yet fires have been so frequent and extensive that much of the forest cover is sparse, soil fertility is markedly depleted, tree growth is stunted, and a normal ground litter is lacking. Particularly in the Cumberlands forest fires and grazing seem to be companions. Fires have been considered necessary by stockmen in order to secure better grazing for the stock which run at large over the mountain fastnesses.

The western loop of the Tennessee River returns through the State after flowing into Alabama and drains a great portion of the western section of the Cumberland Plateau, the Highland Rim, and the Great Central Basin, and a relatively narrow border of the western section of west Tennessee. An area of perhaps 11,000 square miles is embraced, 3,000 square miles of which lie in west Tennessee. Portions in the Cumberland Plateau and the Highland Rim are greatly dissected by the river tributaries, and steep slopes characterize much of the drainage system. These slopes have undergone considerable clearing for agricultural purposes, similar to other lands in east Tennessee. They have terminated with a goodly portion of their areas washed or impoverished to such an extent that they are unprofitable for cultivation. Some of these lands, as elsewhere, can be reclaimed properly for farm crops, yet under present conditions they are not needed and may be profitably and advantageously returned to forest growth. Where fires and grazing have been absent, abandoned fields frequently return quite rapidly to tree growth by natural reseeding.

Although the Great Central Basin is considered the bluegrass and the great farming section of the State, nevertheless it has its share of idle farm lands in the form of steep, eroded hillsides, shallow and rocky soil, and impoverished fields. Vast districts were once covered with virgin red cedar which has played such an important part in the pencil industry. The cedar occurred largely on rocky shallow soil on steep, rolling, and level areas. These districts have been largely exhausted of their stands and the land has been given over too freely for cultivation and pasture, for neither of which the land is generally adapted. These areas, as a rule, have resulted in a great waste when assigned to such uses. They should have continued to produce cedar in mixture with hickory, black walnut, and ash, which develop well in combination with cedar.

The history of numerous hillside lands is written quite plainly on their faces. The lower portions, long since cleared, are frequently found worn out or gullied and given over to pasture with a newer strip of cleared land just above. Still farther up the hillside a recent clearing is found with possibly the top of the hill still capped with a small acreage of trees.

The Cumberland River drains the north central section of the State, including a portion of the Cumberland Plateau, Highland Rim, and Central Basin, which amount to approximately 9,000 square miles. Here occur the more dissected portions of the Cumberland Plateau and Highland Rim, marked by narrow valleys, many sides of which have been almost wholly cleared for cultivation. This has resulted in considerable erosion and soil depletion. Many of these

slopes where rock lies close to the surface have become permanently unfit for cultivation. The same custom prevails here as elsewhere, that of constant clearing, wearing out the soil, and turning it out to be followed by more clearing.

The soil of the two drainage areas just mentioned has a composition of such a nature that it is by no means as highly susceptible to erosion as the area next to be described. However, the topography, character, and management of the cleared land, indiscriminate grazing, and forest fires have a tremendous influence toward rapid drainage.

The direct drainage of Tennessee into the Mississippi River occurs in western Tennessee, in those portions generally called the West Tennessee Plateau and bottom land. This is a rather low rolling section of about 10,350 square miles, which includes both drainage into the Mississippi River and a narrow strip sloping into the Tennessee River. It will be considered as one unit since almost all of it is similar in its reaction to rainfall. It is composed of clay loam and a mixture of sand and clay in such proportion as to render it very easily eroded. Its elevation does not exceed perhaps, 600 feet at any point; its lowest portion being along the Mississippi River. It is traversed by a number of sluggish streams which receive the débris eroded from its neglected, cleared slopes. Here erosion assumes two forms; the perpendicular bank type, and the V-shaped type. The perpendicular type perhaps is the more common. Great quantities of silt wash from badly gullied slopes into the sluggish streams and help to clog the channels, tending to create swamp conditions. It is estimated that there are around one and one-half million acres of swamp land in west Tennessee. This condition is being somewhat changed at present through a system of dredged channels, which have straightened some of the streams. The drained swamp lands are now being cleared for cultivation. The neighboring lands are still giving their loads of silt to these channels which must either carry them along or again be clogged. To date, the new dredged channels seem to be successfully carrying whatever sand and clay is brought into them. The silt burden of these streams finds its way into the Mississippi River.

The major portion of the forests of west Tennessee have been removed, the remainder being almost wholly in farm woods or stands on swamp or dredged lands. There is need for a great many planted forest tracts in west Tennessee in view of the amount of cleared land now lying unused, and also the large acreage of eroded and badly gullied lands. On account of its easily eroded soil and the consequent silt that goes into the streams, western Tennessee is of considerable importance in any plan of flood control. The reclamation of waste areas by black locust and other species, is both encouraged and undertaken by the division of forestry. A State nursery has just been established by the division to aid in this work, and actual reclamation projects have been carried on for 12 years, which look toward future planting with such trees as poplar, oak, and walnut on both gullied lands and other idle areas. Even if all the cleared land in Tennessee were suitable for agricultural crops there would be abundant reason for reforesting a vast portion of the land already cleared. All of it is not now needed for crop production, and until actually needed it should be used for the production

of timber and for contributing its share in other ways to the benefit of the State, one of which is the conservation of stream flow.

As no survey has been made for the purpose, I should hesitate to state the exact area of forests that should remain in Tennessee as a number of factors are involved in the answer. Roughly speaking, however, I should say there should be around 10,000,000 acres. From future development in land uses, it may be found that a smaller acreage will be adequate without serious consequences.

There is need for a vast amount of reforestation both by natural and artificial reproduction. Furthermore the landowner can be a tremendous factor in decreasing rapid run-off by adopting a better system of agriculture. The use of proper cover crops, deeper plowing, and discrimination in choosing fields for cultivation will go a long way in helping prevent erosion and deterioration of soil. A very conspicuous practice resulting in erosion is that of running rows of cotton, corn, and other small crops "up and down the hills." Only a few years of this kind of mismanagement are necessary to destroy the usefulness of areas thus treated. With the elimination of fires from forested areas, the reclamation of eroded sections with forests, the proper regulation of grazing on the forest, and good management of farm woods, together with right forest practices on large forested areas, there is little question that a heavy run-off of rainfall will be greatly controlled.

RUN-OFF AND FLOOD HISTORY

The Cumberland and Tennessee Rivers are the chief streams of Tennessee flowing into the Mississippi River indirectly by way of the Ohio. The other streams of Tennessee which flow directly into the Mississippi are chiefly the Ohio, the Hatchie, and the Forked Deer. From the standpoint of water discharged into the Mississippi River, the Tennessee and the Cumberland are unquestionably the main streams. The months of the year during which their high waters and floods occur are chiefly January, February, March, and April. This is generally true of all streams in Tennessee due to the uniformity and seasonal distribution of rainfall throughout the State.

The Tennessee and the Cumberland carry great quantities of silt during their flood and high water periods, and also comparatively enormous amounts during heavy rains at other periods of the year. They do not, however, shift their channels to any noticeable degree. The west Tennessee streams mentioned above although sluggish and flowing directly into the Mississippi, carry excessive loads of silt during heavy rains, since the soil in that section is of such a mixture of sand and clay that it erodes readily. The heavy silting from neighboring lands has resulted in swamp conditions along the stream channels and considerable filling in of the stream beds. Forests cover most of these swampy, or semiswampy lands along the main stream channels. It is estimated that there are around one and one-half million acres of these wet lands in west Tennessee.

HISTORIC DEVELOPMENT

Tennessee was formerly a vast hardwood forest, dotted here and there with relatively small areas of spruce, hemlock, white pine, and short-leaf yellow pine. Most of the conifers were on the Cumberland Mountain and the Great Smoky Mountain sections; but as a whole, the area might be considered a vast hardwood forest. Those changes which have occurred in the rate of run-off from the primeval state to the present have been caused by the clearing of lands for farms and their subsequent management, forest fires, indiscriminate grazing, and lumbering with the attendant lack of attention in securing new stands.

The forest fires of course remove leaf litter and other forms of vegetation, which have accumulated on the surface, and thereby contribute very largely to rapid run-off. Hand in hand with the forest fire is the grazing problem, the forest fire being considered necessary to secure better grazing. The continued exposure of the mineral soil by forest fires, facilitates rapid drainage and erosion. In the absence of grazing and fire, the quick response of some kind of vegetable growth prevents practically any section from being considered as devoid of cover for any considerable time.

The main agricultural areas to date in Tennessee are the East Tennessee Valley, the Great Central Basin, the West Tennessee Plateau, and a portion of the Highland Rim. The forests of these sections have been largely removed, the remainder being in the nature of farm woods. The major forested areas of the State which remain, therefore, are in the Great Smoky Mountains of east Tennessee, the Cumberland Plateau, the southwestern and northeastern portions of the Highland Rim, and parts of west Tennessee along streams and in the hilly southeast section. These have been promiscuously cut over, with little or no consideration for future stands of timber.

The ownership of land in Tennessee is by private individuals, with the exception of 340,883 acres by the Federal Government and around 100,000 acres by the State.

It is estimated that about five-ninths of the State is cleared land, leaving therefore four-ninths or about 12,000,000 acres in forests of one sort or other. Of this, 2,000,000 acres are estimated to be farm woods. The remaining 10,000,000 acres are distributed in larger forests as follows: The Great Smokies (elevation ranging from around 1,500 feet to 6,800 feet), with perhaps over 1,500,000 acres; the Cumberland Plateau section (elevation 1,000 to 2,200 feet) with 4,000,000 or more acres; the Highland Rim (elevation of around 1,000 feet) with between 3,000,000 and 4,000,000 acres; west Tennessee with the remainder.

CONDITION OF LANDS OTHER THAN FOREST

(*a*) *Improved lands.*—Lands cleared for cultivation, including those which, because of their subsequent run-down condition, have been turned out and not used other than for pasture or to return to tree growth by natural seeding. It is rather difficult to give any concise statement as to improved lands because they have such a broad variance in their physical condition, ranging from the very richest to the very poorest and most poorly cared for. It is estimated that about

five-ninths of the area of Tennessee has at one time or another been under the plow.

The forest lands may in a sense be called forest range, on account of the grazing to which they are subjected. As stated above some of the abandoned farm lands are usually given over to pasture and as a rule contribute their share to rapid run-off, particularly where such lands are on slopes.

There are no chaparral lands in Tennessee, and only a comparatively small area of brush lands (laurel), chiefly in the Great Smokies.

The tillage which is practiced in crop production is frequently responsible for much erosion and rapid run-off: (*a*) Shallow plowing is very effective in producing rapid erosion during heavy rainfall; (*b*) the lack of cover crops during the winter is another factor; (*c*) a third is the custom of cultivating farm crops (corn, cotton, tobacco, and similar ones) with rows running up and down the hill. A change from these practices would be very helpful in maintaining tilled land, and therefore in relieving excessive run-off and erosion.

CONDITION OF FOREST

1. Spruce in Tennessee occurs on two or three of the high summits of the Great Smokies and covers a comparatively small acreage. Hemlock occurs sparsely and in mixture with hardwoods as a rule, chiefly in the Great Smokies; a small quantity of it occurs also on the Cumberland Plateau, particularly along the streams.

Practically the only cedar in Tennessee is the eastern red cedar (Juniperus virginiana). While it grows in almost every section of the State its most abundant production is confined almost exclusively to rocky limestone acres, steep, rolling, or level.

2. The short-leaf yellow pine and the northern white pine are the two chief pine trees in the State. The white pine occurs mainly in the Great Smokies and on the Cumberland Plateau, but not in large quantities. The short-leaf pine occurs in the southeastern portions of west Tennessee.

3. The lowland and swamp types of hardwood occur in west Tennessee, and consist chiefly of soft maple, tupelo gum, gum, sweet gum, sycamore, and river birch, with occasional oaks and sugar maples. These lands are being drained by dredging and straightening out the main river channels. Much of these forests will thus eventually be cleared for cultivation.

4. Practically the whole State might be considered a vast upland hardwood forest with the exception of the lands which have been cleared for cultivation. They have been promiscuously cut over and left with little or no attention given to their future development. Fires have been permitted to burn promiscuously either for no reason at all or for the purpose of assisting grazing.

A. *Effect of lumbering.*—The best trees were removed, the inferior ones left, the tops remaining on the ground. In the absence of forest fires these areas were soon covered again with a dense growth of trees and other forms of vegetation, the trees being generally of the same species as those removed. There is little or no difficulty in securing an immediate ground cover in the absence of forest fires and grazing.

B. *Effect of fire.*—Forest fires have been frequent and therefore have prevented a normal accumulation of ground cover, in the absence of which erosion and run-off have naturally been hastened. The effect of repeated fires is noticed, not only through the removing of the leaf litter, but also in soil depletion and the stunted growth of young trees.

C. *Effect of grazing.*—The effect of stock upon the forests is noticeable on big areas from the damage which they do in browsing young growth, particularly the better species. The number of stock is usually not sufficient to severely injure the soil or ground cover by tramping.

D. *Effect of drainage.*—Drainage on the swamp lands of west Tennessee has resulted chiefly in making more forested lands available to clear for cultivation. The effect of lowering the water table has been of little or no consequence as far as the forest cover is concerned. The dredge channels themselves are apparently invigorated outlets for silt from neighboring lands.

E. *General summary of forest conditions throughout the drainage area.*—Forests throughout Tennessee comprise in brief about 12,000,000 acres of forest land, 2,000,000 of which are in farm woods, usually heavily grazed. The remaining 10,000,000 acres are largely cut over with the exception perhaps of 1,500,000 acres of virgin forest in the more inaccessible regions of the State. Although covered with trees of various species and conditions these forests can be vastly improved by preventing fires, grazing, and indiscriminate clearing, and by the natural and artificial reforestation of a big acreage, particularly the gullied, steep, and shallow-soiled land.

CRITICAL FOREST AREAS

The Great Smoky Mountains (embracing an area of ground 1,500,000 acres) have precipitous rocky sides and should without question be retained in forest cover, without which, or its equivalent if there is such, the section would become an outstanding menace from erosion and rapid drainage. It is therefore most necessary that this particular section have proper consideration in its future development.

The Cumberland Plateau (in round numbers 4,000,000 acres) is exceedingly important in the matter of drainage and erosion, both because of its eastern and western slopes and because of the character of the soil covering the top or plateau proper. Generally this soil is sandy and gravelly in nature, and therefore fairly easily eroded. It is furthermore characterized by deep narrow gulches whose sides should be protected by forest cover. Sandstone and shale usually lie close to the surface throughout much of the section.

West Tennessee (around 6,600,000 acres) becomes a critical area in drainage because of its easily eroded soil, which finds its way into the stream channels, and finally into the Mississippi River. However, all of the surface soil in west Tennessee responds as quickly to good treatment as to bad; consequently the erosion problem there becomes largely a matter of proper care of the soil. Much of the area that has been cleared is not needed for cultivation at present, and probably will not be for the next 100 years under normal population increase. Much of this idle land in western Tennessee should

be returned to forest growth until there is an actual demand for its use for tillage.

In the valley of east Tennessee, the Great Central Basin, west Tennessee, and portions of the Highland Rim, the forested lands occur chiefly as farm woods (except the woodlands along the swamps and stream channels of west Tennessee). These acreages should be much increased using those lands which have been worn out, those whose surface is eroded, and those which will serve a better purpose if returned to forests. This can be done to a great extent by artificial planting. Much of the land in the meantime can be returned to forest growth by natural reseeding in the absence of grazing. Fire on these farm woodlands is almost negligible. However, the custom of grazing farm woodlands is quite prevalent. This results in the deterioration of the farm woods first into areas of undesirable scrubby trees, and under continued grazing to scattered trees, which ultimately gives the land over for cultivation. Thus the proper management of the farm woods is an important factor in retaining them as a protection against erosion.

RECOMMENDATIONS FOR THE WATERSHED

A. A sufficient survey of the forested area of the State has not been made to justify me in making any definite statement regarding the acreage that should be retained in forests. The topography of the State is very greatly diversified, and many hillsides that are now tilled will in the end revert to forests, because they can not be retained economically in tillage or in pasture. However, venturing a mere guess from my analysis of the State's topography, I should say that in the neighborhood of 10,000,000 acres should be eventually the forest area in the State; yet so many factors appear in considering a matter of this kind that even those figures may prove to be far out of line with the final record.

B. Measures necessary to keep present forest land productive. Consider:

1. A well protected forest with normal stands of the best species naturally affords the best ground cover and protection from erosion. Protection against fires and grazing restrictions are essential to this end.

2. A small portion of Tennessee in Polk County is affected by smelters. The conditions there are proof that forests can not exist in the presence of unbridled smelter activity.

3. The ease with which reproduction is assured in Tennessee practically insures forest perpetuation without replanting if fires and grazing are prevented. This is particularly true where clear cutting and the selective method are used. The ground usually restocks itself with one or more of the species present before the cutting was made.

4. On areas once cleared for cultivation a certain amount of forest planting should be done to secure the desired species and also to hasten reforestation on lands which are greatly in need of it. In the meantime if grazing is restricted many areas will restock themselves through natural reseeding.

5. A certain amount of stock ranging can be permitted on forest lands, particularly on the larger areas, or where forests develop

normally. However, under proper forest management, forests generally should contain very little vegetation that stock choose to eat. The grazing obtainable on properly cared for farm woods is also negligible, and consequently of little profit. In my judgment, therefore, the profits derived from grazing in forests of Tennessee do not exceed the amount of the injury done by tramping of the stock. Such areas merely constitute tramping places over which the stock can range.

APPENDIX VI

ANALYSIS OF RUN-OFF AND FLOOD INFLUENCES IN THE MISSOURI BASIN

M. H. Wolff, *Assistant District Forester*

INFLUENCES OF MISSOURI ON FLOODS OF MISSISSIPPI

Major General Jadwin has said, "It must be borne in mind that it is generally not the water flowing out of the mountain streams but rather the rains falling on the alluvial basin of the river itself that create the greater part of the floods of the Mississippi." Capt. A. B. Jones of the flood-control office, of the Engineer Corps of the United States Army, is authority for the statement that any waters which come from any portion of the Mississippi drainage lying west of the ninety-seventh meridian have so little influence on the Mississippi flood flows that it is evidently not worth while to make any expenditure to regulate them. The Missouri crosses the ninety-seventh meridian just above Sioux City, Iowa. This, of course, does not take into account the effect of silt carriage due to erosion, a considerable quantity of which is brought down from some of the lands west of the ninety-seventh meridian and augments the silt burden of the lower portions of the Missouri.

The floods of the Mississippi are considered by the Flood Commission to occur primarily between February 15 and May 15. The peak flows of the upper basin do not come till June. It takes about 25 days for these waters to reach the Mississippi. This would indicate that they would not affect the Mississippi till about July 1. There have not usually been destructive floods in the Mississippi at this late date. The highest water ever recorded in the upper Missouri, in 1908, peaking sharply between June 1 and June 5, was not reflected appreciably in the Mississippi. Even the normal flows in the upper tributaries, although they add just so much to the total quantity of water that has to be handled, have no great influence on the Mississippi. The normal flow in the upper Missouri and its upper tributaries from about January 15 to April 15 is ordinarily very low.

An examination and study of hydrograph curves prepared by the United States Army Engineers of the Flood Commission indicates that in the floods since 1911 of the lower Mississippi, the total contributions of the Missouri approximated one-eighth of the waters flowing past Cairo. The highest contributions at any time were somewhat less than one-third of the 1,500,000 cubic feet per second flow at Cairo on April 28, 1927, less than one-third of the 1,500,000 cubic second-feet flow on April 24, 1922, and between one-fifth and one-fourth of the 1,000,000 to 1,400,000 cubic second-feet flowing past

Cairo, in May and June, 1927, with the contribution during remaining dates of flood stages at Cairo generally under one-tenth.

The waters flowing past Sioux City in the main stream, contributing to the Mississippi floods during this period of years approximated much less than one-twentieth of the flow past Cairo. They made a maximum contribution of about one-sixth of the 1,000,000 cubic feet per second flow past Cairo on May 23, 1927, about one-tenth of a flow of a million cubic feet per second on April 16, 1916, and about one-twelfth of a flow of 1,500,000 cubic feet per second on April 18, 1913. At other times the contributions were well under one-twentieth.

As an index of what one of the lower tributaries may do, the Flood Commission records show that of the high waters flowing out of the Missouri to make a flow of 1,850,000 second-feet at Cairo on February 6, 1915, the Missouri contributed about 200,000 cubic second-feet, or 11 per cent; and of this 200,000 cubic second-feet the Osage contributed 150,000 cubic second-feet, or 75 per cent, or about 8 per cent of the total Mississippi flow at Cairo. On April 24, 1922, the Missouri River contributed 30 per cent (460,000 cubic second-feet of a total of 1,550,000 cubic second-feet); and of this 30 per cent the Osage itself contributed about 30 per cent, or about 9 per cent of total Mississippi flow past Cairo. On April 20 the highest 1927 flood peak at Cairo occurred; the Missouri altogether contributed about 20 per cent of this flow and the Osage contributed about 30 per cent of that, or 6 per cent of the total.

Than by the Osage there is no evidence of any material contribution to any of the Mississippi floods by any other major tributary. Apparently the rest of the extra contribution of the Missouri came from the many small tributaries emptying immediately into the Missouri, or from the run-off from the immediate slopes of the Missouri River itself. It is estimated from the War Department records that the tributaries of the Missouri contributed the following percentages to the flows at Cairo at times of Mississippi floods during the last 15 years:

Gasconade River about 1 per cent.
Osage River about 3½ per cent.
Kansas River less than 1 per cent.
Platte River less than 1 per cent.
Yellowstone River less than 2 per cent.
White River, S. Dak.; Grand River, S. Dak.; Moreau River; Musselshell River, and Marias River all negligible.

Table AD–I, prepared from the records of the flood commission, shows in thousand cubic foot seconds a number of representative flows past various points of the Missouri River. For each point is given the number of days which it takes the flow to reach Cairo. The table also shows the dates on which the flow at Cairo reached a million cubic feet per second and 1,500,000 cubic feet per second and the date of the peak point of each flood and the size of the peak. The flow figures for each point on the Missouri represent the amount of water which passed that point which theoretically should reach Cairo on the dates indicated for Cairo; that is, the lag has been taken care of in the table.

In considering these figures, it is to be borne in mind that it is recognized by officers of the flood commission that these figures have

a number of elements of inaccuracy. But they are the best obtainable; they are given, since they furnish an index of some value.

This table shows quite well that the run-off from that portion of the Missouri basin above approximately Sioux City has but little influence on most of the flood flows of the Mississippi at Cairo. There are, however, some exceptions and unquestionably even that small influence is worthy of consideration.

CONTRIBUTING CAUSES OF FLOODS AND HIGH WATERS

A limited analysis of the conditions of the time of the three greatest recorded flood flows at Fort Benton, Mont., gives an index of the contributing causes of high flows in the upper tributaries of the Missouri that drain the timber belt. It appears that three meteorological factors contribute to cause excessive flowage. Probably the most important is the heavy rain in May and June which adds to the run-off from the normal snow melt. The second is an abnormally heavy snow melt resulting from greater than usual snowfall. Third, and probably not the least, is a condition resulting from temperatures. When it happens that a normal winter snow blanket held abnormally late into the spring by distinctly subnormal temperatures is subjected to normal or higher temperatures in May and June, high flood flows are imminent even though the April, May, and June rainfall is normal or subnormal. Such a condition existed in 1917, when the second highest recorded flow occurred. The importance of retarding snow melt is thus emphasized. This influence is exerted by the forests, occurring as they do in localities of heavy snowfall.

In other portions of the semiarid region, high flows occur as the result primarily of rains.

The Milk River, the Powder River, and the smaller tributaries of the main Missouri drainage in eastern Montana and the Dakotas have rather flashy run-off records. By monthly periods they have on the average moderately abnormal run-off in March or April, and a major rise in June. The first is attributable to the spring snow melt, the second entirely to May and June rains. The earlier high flow comes in time to add somewhat to the Mississippi at times of its flood.

Except for the moderately accelerated run-offs in early spring, it is apparent that the heavy flow from this portion of the Missouri rather than affecting the flood flow of the Mississippi, tend instead to sustain the flow of the lower river after the deliveries of its flood-contributing tributaries are completed. From this view also is delay in the snow melt in the forested tributaries of this portion of the basin, a desirable feature.

The flood flows of the tributaries and those portions of the major stream, which lie in the semihumid belt, come from the rains. There is no snow blanket to amount to anything. On the whole, the normal flow from springs is not high. The run-off conditions of the soil and cover are not conducive to retention of any great proportion of the precipitation. The precipitation totals high, and is often concentrated. The lower tributaries rising in the semihumid belt are hence comparatively distinctly flashy.

RELATION OF PRECIPITATION TO RUN-OFF

Data for comparing the periodic precipitation over the whole Missouri drainage with run-off therefrom are available by units only for that portion of the Missouri above the mouth of Cheyenne River. The information thus obtained is given as indicative. In graph AD–1, the winter months were omitted because data on run-off are so meager. This graph indicates that the difference between total average precipitation and the total average run-off for the months in question is a little over 13.5 inches. This represents a loss due to evaporation, percolation, transpiration, and water used in building up vegetable matter. This figure corresponds roughly to approximations of this loss accepted as within reasonable limits of error by Mr. Robert U.

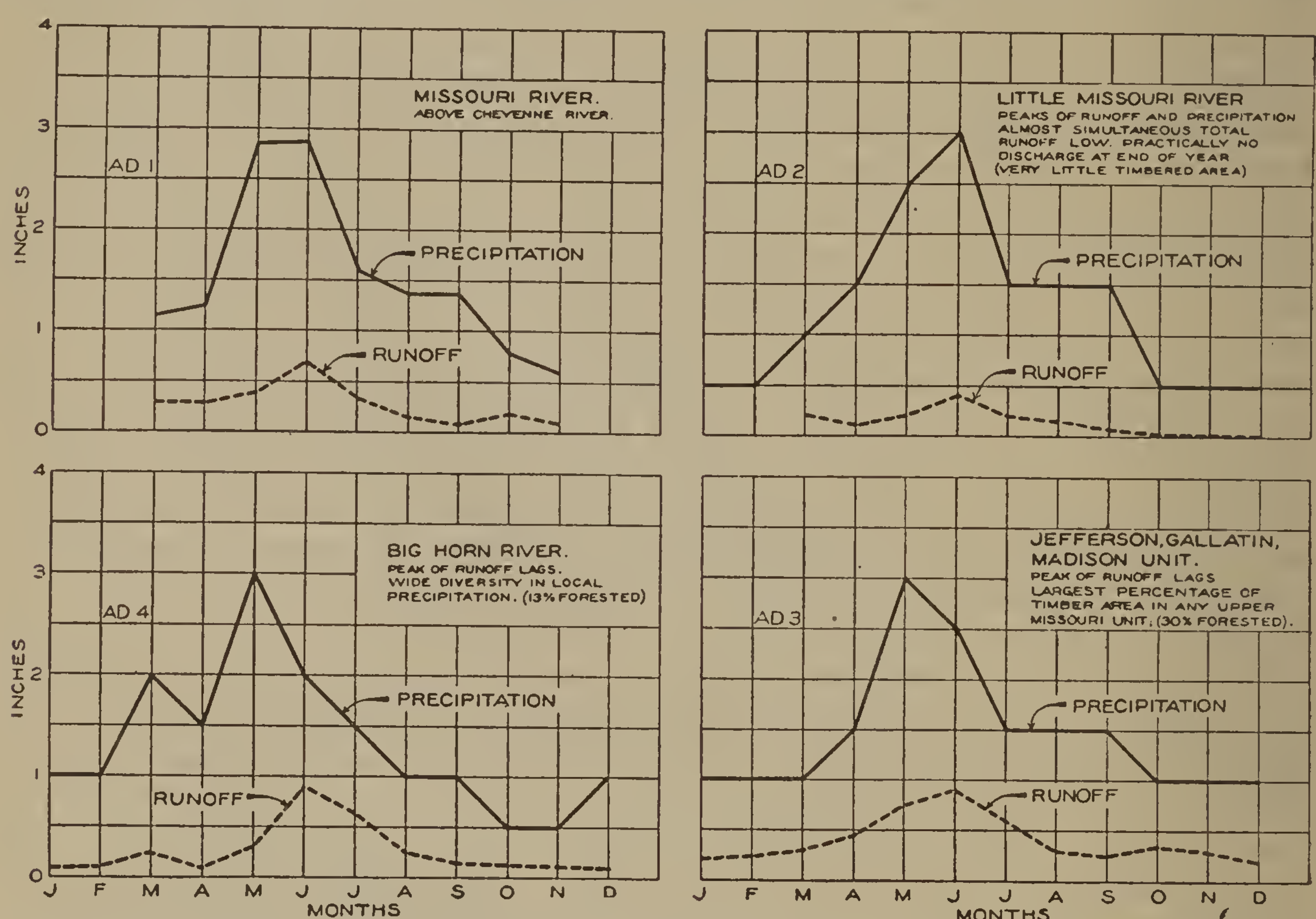

FIGURE 23.—Relation of average monthly precipitation to run-off. (Precipitation from Atlas of a American Agriculture, Part II, section A, 1922. Run-off from Annual Water Supply Papers, U. S. G. S.)

Follansbee, hydrologist of the United States Geological Survey, for the Rocky Mountain district. He states that losses between precipitation and run-off average annually 15 to 20 inches. He uses in his calculations in the Rocky Mountain region the figure of 15 inches.

This graph also shows that the high period of precipitation is followed some period later by the high point in run-off—by the method used this shows up in the following month. An interesting indication also is the slight rise in run-off in October. This appears due to the continuance of even rate of precipitation during the months of August and September, which, together with probably less evaporation with the coming of cooler weather, apparently turns back the consistent drop in run-off from the peak in June. It is also again brought out that the high flow of June is of no effect on the Mississippi floods, which are considered to fall within the period February 15 to May 15 by the Army Engineers assigned to flood-control work.

Graphs AD–2, AD–3, and AD–4 indicate an interesting trend. In the Little Missouri unit—practically untimbered and without high mountains, and having a high proportion of bad lands—the peak of average monthly run-off corresponds with the peak of average monthly precipitation. On the other hand, in the other two units, having more timbered and high-mountain reservoir country, even though one of them has an appreciable proportion of bad lands, the average run-off peak lags about a month behind the average precipitation peak. It is also to be noted that the proportion of run-off to precipitation is high in the more heavily timbered units and that there is apparently a greater consistency in average flow month by month. The high proportion of May precipitation in the mountainous units coming as snow, and hence not adding to the run-off, is assumed to be offset by the increase in flow from melting snow accumulated during the winter at the lower altitudes.

Figures to enable comparison by units of average annual precipitation with average annual run-off are available for only a portion of the units. The following table is largely self-explanatory.

Comparison of run-off and precipitation

[For the units omitted, data are not available]

Unit and number	Area (square miles rounded off)	Area forested (square miles rounded off)	Per cent of area forested	Per cent of area in mountains	Mean annual precipitation in inches	Mean annual run-off in inches	Losses in inches	Ratio of run-off to precipitation
43. Gallatin, Madison, Jefferson	13,950	4,850	35	40	[1] 17.5	4.75	12.75	0.27
44. Little Missouri	9,350	100	1	0	15.0	1.75	13.25	.12
45. Marias	7,100	375	5	7	16.5	5.25	11.25	.32
46. Milk	15,000	325	2	4	14.5	.75	13.75	.05
47. Missouri (direct)	52,700	400	1	0	17.5	1.25	16.25	.07
48. Musselshell	9,600	975	10	5	16.0	2.50	13.50	.16
49. Upper Missouri	26,850	3,025	11	15	[1] 17.0	5.00	12.00	.29
50. Big Horn	23,050	3,000	13	30	[1] 16.0	3.00	13.00	.19
51. Powder	13,500	500	4	5	15.0	1.25	13.75	.08
52. Yellowstone (direct)	33,650	4,225	13	20	[1] 16.0	3.50	12.50	.22
For all of above	204,750	17,775	9	8	16.5	2.75	13.75	.17
Whole Missouri River	525,000	40,000	7.5	----------	[2] 21.0	[3] 2.13	18.87	[4] .10

[1] It is not improbable that Weather Bureau records are conservative in regard to precipitation in the high mountains of these units. This is strongly maintained by Mr. Robert Follansbee, hydrologist for the U. S. Geological Survey for the Colorado-Wyoming territory.

[2] Weighted average from Weather Bureau records.

[3] Based on figure of 0.157 second-feet per square mile for 528,000 square miles given by Dole and Stabler in article on Denudation, p. 89 of Water Supply Paper No. 234.

[4] In Water Supply Paper No. 234, p. 55, M. O. Leighton, in article on Developed Water Powers gives annual run-off of 2.41 inches, which is based on an estimated second-feet flow of 94,000 obtained from the 1891 Annual Report of the Chief of Engineers, p. 3826. J. A. Ockerson, on Flood Control of the Mississippi River, p. 1168 of the 1922 Proceedings of American Society of Civil Engineers, gives the mean annual precapitation (based on Bulletin E, U. S. Weather Bureau, 1897) of 19.4 inches. These two figures would indicate a ratio of 0.12. Humphres and Abbott, on p. 84 of the Report on the Mississippi River, 1861, give an average precipitation of 20.9 inches and an estimated drainage area of 518,000 square miles with a mean annual discharge of 120,000 cubic-foot seconds, which gives a ratio of 0.15.

This table evidences a rather distinct trend. There is a high ratio of annual run-off to annual precipitation for those units which contain appreciable proportions of area under forest or at high elevations, both of which tend, first, to promote delayed run-off, and through that to stimulate percolation; and, secondly, to decrease

evaporation. There are two units which seemingly are out of line with this trend. The Marias, 5 per cent forested and 7 per cent mountainous, shows a 0.32 ratio between run-off and precipitation, a rather distinct inconsistency with the trend; and the upper Missouri, 11 per cent forested and 15 per cent mountainous, shows a 0.30 ratio between run-off and precipitation, a somewhat lesser inconsistency. Part of these inconsistencies is undoubtedly attributable to errors in the basic data which are inevitable because of paucity of records. The inconsistencies in the case of the Marias may be accounted for by the fact that the only available gauging station records are for a drainage area of only 2,600 square miles out of a total of 7,200 for the unit, and that these 2,600 square miles include all the mountainous and forested lands in the unit. By the usual method accepted by hydraulic engineers the run-off for the whole 7,200 square miles was obtained from the available figures on a proportional basis. This adjustment probably gives a run-off for the whole unit which is considerably high. In the case of the upper Missouri the error may be the result of inaccuracies made in necessary adjustments to subtract from the main stream flow the flows of the tributaries which comprise separate units. Or the figure may be correct but higher than would be expected because the short average lengths of the lateral feeder drainages included in the unit and their short average distance from the major watercourse would enhance run-off effect in the main stream.

SILT CARRIAGE

Very meager data are available on the silt content of the stream. It is known through general observation that, on the whole, the main tributaries are clear as they come from the wooded, mountainous districts, even in times of high water being no more than colored; and that they gradually pick up sediment and lower down are heavy silt carriers even in low-water stages.

From an article on Denudation, by Dole and Stabler, in United States Geological Survey Water Supply Paper No. 234, a few figures are available. At Havre, Mont., the solid burden per annum is 25 tons per square mile of drainage basin in solution and 46 tons per square mile in suspension. An Glendive, Mont., the Yellowstone River carries 70 tons per square mile in solution and 158 tons in suspension. The Missouri River near its mouth carries 50 tons per square mile dissolved, and 290 tons suspended. The Missouri River then brings down annually a little over 25,000,000 tons in solution, and a little over 150,000,000 tons in suspension.

Theoretical calculations of erosion on the Grand River in Iowa and Missouri, based primarily on erosion investigations of the University of Missouri, indicate that that stream alone carries away an eroded tonnage of about 8,500,000 annually. This high proportion (about 5 per cent of the annual silt burden of the entire river, coming off about 1.4 per cent of the area) is largely the result of the extension of the cultivated area and injudicious methods of tillage.

From a table in an unofficial document of the War Department, there was obtained the information that the annual discharge of solid matter of the Mississippi amounts to 518,500,000 cubic yards,

and that that of the Missouri to 413,000,000 cubic yards. This means that 80 per cent of the silt carried by the Mississippi comes from the Missouri if, as seems fairly reasonable, it be assumed that the income and the outgo of silt in the Mississippi below Cairo are fairly stabilized in relation to each other.

All this heavy silt carriage in the lower portions of the stream, together with gradual slowing up of the current as the result of decrease in general slope, is reflected in the progressive increase of sand and silt bars, and sandy islands in the streams. The lower tributaries with their flat trajectories at their lower reaches are similarly characterized.

The shifting of channel and the gradual filling up of one portion or another of the streams has always been a source of difficulty in navigation. As with the main stream, navigation is kept possible only through continuous engineering effort.

APPENDIX VII

DESCRIPTION OF THE ARKANSAS RIVER

W. W. Ashe, *Senior Inspector, Eastern National Forest District*

The main Arkansas River ordinarily receives little water from its upper tributaries save in time of floods. In topography and characteristics and in the difficulties of its regulation the Arkansas is in many ways typical of the rivers in the arid regions of the Western States, two of which are among its tributaries.

The source of the permanent flow of the main Arkansas River as far east as the Kansas State line is the snow fields of the Continental Divide. The rapidly melting snow waters of May and early June are reinforced by the severe rains on the upper plains and foothills—heaviest during summer.

During the past few years, its dry season flow in the headwater province and through western and middle Kansas is largely sustained by the snow melt of summer. The summer flow is decreased owing to the fact that so much is taken out during the growing season for irrigation purposes near the head of the river. In central Kansas there is little doubt that the supply is less for this reason than in former years.

Notwithstanding the low rainfall on the middle and upper portion of the basin of the Arkansas River and its tributaries below the mountains, there are numerous springs. They occur in the sandhills which lie chiefly to the north of all of the larger streams except the main river, but to the south of it chiefly, and which extend from near the eastern line of Colorado as far as the eastern limit of the low plains. Bold springs are less frequent, however, in the high plains region, and throughout this region the springs flow out near the river on both sides of the streams, but farther eastward they appear chiefly along the divides forming the headwaters of the tributaries. None of the sandhills springs have been known to go dry during the droughts which are common to the region, although they sometimes diminish in flow.

Although there is considerable underflow to the main Arkansas River in middle Kansas and its upper reaches in crossing the Flint Hills, this underflow is forced to the surface lower down and for that reason the channel rarely runs dry in this part of the stream. The shores are sandy clay, or loam throughout some 1,300 miles, with very rarely rock ridges or rapids, and the banks rise low above ordinary water. The waters are constantly rising and falling, and almost never is the discharge at any point uniform.

On the lower reaches of the Arkansas River—

every year there are, normally, two distinct periods of high water; one an early freshet due mainly to the heavy winter rainfall on the lower river, when the upper river is still frozen hard; the other in the late spring, due to the setting in of

rains along the upper courses also, and to the melting of the snow in the mountains, though this causes only local floods. The lowest waters are from August to December. In the summer, on the other hand, there are sometimes violent floods on the tributaries due to cloud-bursts. Everywhere along the river there is a never-ending variation of velocity and discharge, and an equally ceaseless transformation of the river's bed and contour. These changes become revolutionary in times of flood. All these characteristics are accentuated below Little Rock. The depth of water at Little Rock has been known to vary from 27 feet to only half a foot, and the discharge to fall to 1,170 cubic feet per second. There is often no more than 1.5 feet of water, and far below Little Rock a depth of 3 feet on crossings is not infrequent. In many places there are different channels for high and low water, the latter being partly filled by each freshet and recut after each subsidence; and the river meanders, tortuously, through the alluvial bottom in scores of great bends, loops and cut-offs.

It is estimated that the eating and caving of the shore below Little Rock averages 7.64 acres per mile every year (as against 1.99 acres above Little Rock). By way of the White River cut-off the Arkansas finds an additional outlet through the valley of that river in times of high water, and the White, when the current in its natural channel is deadened by the backwater of the Mississippi, finds an outlet by the same cut-off through the valley of the Arkansas. This backwater, where it meets and checks the current of the Arkansas, occasions the precipitation of enormous alluvial deposits and vast quantities of snags. The banks are disintegrated along this part of the river and built up again on the opposite side to their original height in the extraordinarily short time of two or three years, the channel remaining all the while narrow. At the confluence of the White, the Arkansas, and the Mississippi the level of recurrent floods is 6 to 8 feet above the timber-bearing soil along the banks, and all along the lower river country the land is liable to overflow. As the land backward from the stream slopes downward from the banks heaped up by successive flood deposits, each overflow creates along the river a fringe of swamps. These features, although exaggerated in the portion of the river now in question, are qualitatively characteristic of its entire course below the mountains.

It is a significant fact that the alluvial lands along that portion of the Mississippi River just above the mouth of the Arkansas River are higher near the river than at a distance back from the river, and the immediate drainage of these alluvials is away from the Mississippi River and into the Current River, a tributary of the White River. That is, the silt deposits on the flood plain have accumulated more rapidly near the bank of the Mississippi River and have eventually resulted in diverting the immediate drainage of the flood plain away from that stream. This building up, if natural agencies have full control, can continue until the river makes a new channel through the lower lying portion of the alluvial land and resumes its prehistoric course along the present channel of this portion of the Current River.

The South Canadian River, the largest upper tributary, has sources fed by springs on the forested slopes of the Sangre de Cristo and other high mountain ranges. Soon after reaching the plains it enters a canyon 500 to 800 feet deep out in the Dakota sandstone and flows through it until the Permian red beds are reached not far west of the Texas-New Mexico State line. For about 150 miles its course then is through the red beds in a valley 10 to 20 miles wide cut deeply into the high plains.

The sides of the gorge constitute a portion of the escarpment with its badlands structure of short, sharp ridges largely destitute of trees and often destitute of vegetation, separated by V-shaped valleys. The flood plain 1 to 5 miles wide occupies the bottom of the gorge 600 feet below the level of the high plains. The river lands, consisting of a sandy bed, vary in width from half a mile to more than a mile. It is constantly shifting, excavating sand in one place and depositing it in another. These slopes—"the breaks"—are the most rugged on the south side. On the north side, especially to the east of the one-hundredth

meridian, there are extensive areas of sand dunes which border not only the South Canadian River but also the North Canadian River, the Cimarron River, Wolf Creek, and a number of smaller streams.

"The breaks" extend eastward about to the ninety-ninth meridian, but the stretches of sand continue, though interrupted, practically down to the confluence of the Arkansas River. "The breaks" are rapidly eating back into the high plains.

The Canadian River is perhaps more treacherous than any other stream of the plains. The stream is either dry or a raging torrent. The river may have been dry for weeks at a time when suddenly without warning a wall of water several feet high rushes down the channel sweeping everything before it. For a number of days the river continues high and gradually subsides. Following these periods the sand in the streams becomes quicksand.

The source of the sudden and rapid rise is ascribed to heavy rains near the head.

However, such floods are by no means limited to the main stream. The small tributaries as well as the North Canadian and the Cimarron Rivers exhibit this same phenomena, and have in general the same type of topography and the same character of channel and of erratic flow.

The dry Cimarron and the North Canadian Rivers, both of which rise in the high plains, are typical plain streams largely dry during most of the year and subject to sudden and high floods during the summer—the period of short but torrential rains of the cloud-burst type.

APPENDIX VIII

TYPES OF FLOODS AND DISCHARGE CHARACTERISTICS OF THE ARKANSAS RIVER

W. W. Ashe, *Senior Inspector, Eastern National Forest District*

Three types of floods occur on the basin of the Arkansas River:

1. The sudden or cloud-burst type is a result of the class of rains known as cloud-bursts which occur particularly on the mountain tributaries of the headwaters and on the plains streams. These are frequently confined to small areas, and while their damage is local, it may be severe. The Pueblo floods of June 3–5, 1921, while the most destructive of this class, were characteristic in their causes and the movement of the flood waters.

2. The local prolonged storm type characterizes the floods on the tributaries within the plains region. These usually affect a wider territory and may cover a longer period in the gathering of the flood waters than those of the cloud-burst type. They may occur at almost any season of the year, but are usually due to prolonged summer and autumn rain storms. The floods of middle-eastern Kansas which have at times inundated Emporia, located between the Cottonwood and Neosho Rivers, are of this type, the latest of such floods being in August, 1927.

In floods of both the first and second types neither soil nor subsoil need necessarily be saturated. The rainfall is so rapid that the air is expelled from the soil too slowly to permit the absorption of a large amount of water. The water largely runs off the surface, the heavy downpour compacting and puddling the top layer of soil which sheds water instead of absorbing it. Any condition of surface which will promote absorption or which will hold back a portion of the surface water will ameliorate the destruction resulting from floods of these classes. Forest or grass cover is of enormous benefit as a means of control in either case.

3. The general prolonged flood, the third type, is the result of general and prolonged rains. On the basin of the Arkansas River floods of this character usually take place in the spring or early summer though not always, as is shown by the flood period of October, 1926, when from October 1 to October 26 the Arkansas River was at flood stage, about 22 feet at Fort Smith, chiefly on account of water contributed by the Neosho and Verdigris Rivers. In the spring the earth is already partly or entirely saturated from the rains and snowfall of the preceding winter, only a small amount of which has been lost through plant evaporation or through transpiration by vegetative power. Such floods are usually the accumulated effects of widespread precipitation often over long periods. They affect the larger streams as well as the smaller. It is this type which is responsible

for most of the floods in the main channel of the Arkansas River, and for those of the White River, and for the floods in the lower Mississippi Valley. It is usually the upper few feet of the water in the flood crest which occasions the greatest loss. Levees constructed to take care of floods are menaced by the extra high waters. Bridges, buildings, railway tracks, and highways are located so as to be safe from all except the exceptional flood crests. If this extra amount of water can be withheld or can be distributed, far less damage will be done.

FACTORS DETERMINING MAXIMUM DISCHARGE

The maximum discharge of a stream depends on several quantities. Primarily it is dependent on:

(1) Extent, duration, and intensity of precipitation, especially the latter in the case of small drainage basins.

(2) Direction of motion of the storm causing the flood. If the storm moves in the direction of flow of the stream the intensity of flood will be greater than if it moves in the opposite direction or across it.

(3) The amount of snow on the ground and the temperature during the storm. Large floods are often due largely to melting snow when the ground is frozen, and in such cases the run-off is much larger than the rainfall.

(4) The storage, both natural and artificial, in the drainage basin. Storage spreads the flood over a larger period and thus reduces the maximum rate of flow.

(5) The size of the drainage basin. Rainstorms of great intensity generally cover a comparatively small area, and a larger part of a small drainage basin is more likely to be covered by a very intense storm than of a larger basin. The maximum discharge per square mile will, therefore, increase as the size of the drainage basin decreases.

(6) The physiography of the drainage basin. The maximum rate of flow from a comparatively long and narrow drainage basin, with tributaries entering a considerable distance apart, will be less than from a basin of nearly circular shape of the same size, but with the tributaries entering the main stream in close proximity. Steep, impervious, deforested slopes of drainage basin, steep slope of bed of tributaries, and small slope of main stream intensify flood flow.

Among the more or less artificial conditions that increase the flow may be mentioned controlled storage in the basin; deforestation and cultivation; reduction in width of channel by placing abutments of bridges in the stream; the use of piers that prevent scour of bed, collect drift, and hold back a part of the flow for a time, causing a greatly decreased flood wave; the formation of ice gorges; and the failure of dams and reservoir walls.

Freshets occur in all streams, usually once a year, sometimes two or more times a year; great floods that result from natural causes occur at irregular intervals, varying from a few years to many years apart. It is impossible to predict the time of their occurrence or determine whether the largest recorded flood is the largest that will occur.

It is very difficult to measure the discharge of a stream at maximum stage with accuracy. At such a time the stream usually carries much drift, overflows its banks, and changes its stage rapidly, all of which makes accurate measurement of flow difficult. (E. C. Murphy, 1904.)

It is thus evident that other factors than the mere volume of precipitation are important in determining the height reached by floods. This is particularly the case in respect to floods of the cloud-burst and local prolonged types, to which the streams which make up the Arkansas River system are particularly subject.

The maximum rate of flow up to the dates given for certain streams on the basin of the Arkansas River in second-feet per square mile is as follows:

	Drainage area	Date	Maximum second-feet per square mile	Duration
	Square miles			*Hours*
Canadian River, French, N. Mex	1,478	October, 1904	105.56	0.5
Canadian River, Taylor, N. Mex	2,832	do	32.11	7.0
Canadian River, Logan, N. Mex	11,440	do	12.29	12.0
Purgatory River, Trinidad, Colo	742	Sept. 30, 1904	61.2	

Maximum and minimum stages.—The following table gives the maximum and minimum stages of the Arkansas River and its important tributaries:

Name of stream	Maximum flow, cubic feet per second	Minimum flow, cubic feet per acre	Ratio of minimum to maximum
Arkansas River at mouth	610,000 (Apr. 21, 1927)	1,000	1 to 600.
White River at Clarendon, Ark	402,000	4,500	1 to 89.
Current River			1 to 65.
Verdigris River	35,000 (Apr. 25, 1922)	150	1 to 366.
Neosho River	100,000 (June 27, 1916; May 1, 1927)	500	1 to 500.
South Canadian River	7,000 (Apr. 3, 1912)	20	1 to 350.
Cimarron River	9,000 (June 27, 1916)	20	1 to 450.
North Canadian River	10,000 (June 27, 1916)	100	1 to 100

The North Fork Canadian and Cimarron Rivers are dry in much of their course during most of the winter and fall.

APPENDIX IX

FLOOD CONTROL BY STORAGE ON ARKANSAS-WHITE RIVER BASIN

W. W. Ashe, *Senior Inspector, Eastern National Forest District*

The streams which make up the Arkansas-White River system have two channels; the low water or ordinary channel from bank to bank, and the flood plain or emergency channel. Damage and loss of property as a rule are the result of encroachment upon this emergency channel, the flood plain, or alluvial lands. This channel is an important part of the drainage of the stream. The stream has developed it to take care of its storm waters. It is these storm waters for which the emergency channel has been developed by the stream which must be taken care of where the levees encroach too far upon the emergency channel. If horizontal expansion is no longer possible, provision must be made for vertical expansion. As a rule, provision has been made for taking care of usual floods, but not for the exceptional floods. It is consequently as a rule only the upper few feet, sometimes in fact only the upper foot, of the flood crest that is responsible for the enormous damage. It is only to taking care of this surplus that consideration need be given. In prolonged floods, such as typify the larger streams, the earth is often fully saturated. It is only by supplementing the earth's storage capacity that this surplus water can be taken care of, and such means of taking care of the surplus water are designed not to replace levees and mechanical means of combating the ordinary menace of high water, but as a further safeguard under emergency conditions, for in no large watershed can all flood contingencies be fully anticipated.

The Federal flood control act of May 31, 1924, calls for reports by the Board of Engineers for Rivers and Harbors with a view to the control of floods on the following tributaries of the Arkansas River:

Canadian River in New Mexico, Texas, and Oklahoma.
North Fork Canadian River in Texas and Oklahoma.
Deep River in Oklahoma.
Verdigris River in Oklahoma.
Little River in Oklahoma.
Cimarron River in New Mexico and Oklahoma.
Arkansas River in Kansas, Oklahoma, and Arkansas.

A preliminary report only a few pages in length has been transmitted to Congress covering the work so far done under this act, but this report apparently has not yet been printed.

ARTIFICIAL STORAGE AND RESERVOIRS

Ozark Province.—Several reservoirs are in existence on the White River and plans have been prepared or are under consideration for

the construction of a number of additional reservoirs, all of them, however, primarily for power purposes. The James River has good possibilities for the development of water power and storage in connection with the main White River. On the White River, about 2 miles above Forsythe, there is a hydroelectric plant with a capacity of 18,500 horsepower, the reservoir having a dam 50 feet high.

The Empire District Electric Co. has obtained a preliminary permit to build a hydroelectric plant about 7 miles above Branson. It is proposed to construct a dam 100 feet high developing 320,000 horsepower. There are other good sites for dams having large reservoir capacity both above and below Forsythe. Black River drains a large part of Reynolds and Wayne Counties and has a rough, hilly basin largely in woods. The flow of the river is fairly uniform. Willis H. Meredith has obtained a preliminary permit for the construction of a dam 3 miles above Leeper which is intended to serve both for the development of electric power and to reduce the flood loss along the lower stretches of the river. The tentative plan looks toward the development of about 30,000 horsepower.

Current River, a northeasterly tributary of the White River, has a basin the upper part of which is very rough and hilly, the lower part rolling; the soil a stony loam, most of the land in timber. The ordinary flow of the river is derived almost entirely from springs which accounts for the extraordinary uniformity of the flow. The low-water flow is larger than that of any other stream of equal size in the State of Missouri. Floods which go over the bottom lands occur occasionally but only after extremely heavy rains. The ratio of maximum to minimum flow is only 65 to 1.

The exceptionally uniform flow and the presence of numerous good dam sites provide very good possibilities for the development of water power. The Missouri Hydroelectric Power Co. has a preliminary permit for the construction of two or more projects between the mouth of Jacks Fork and Doniphan calling for about 100,000 horsepower. There are other available sites.

Eleven Point River drains a hilly basin mostly wooded and with stony loam soil. On account of the many springs, the flow of the river is exceptionally uniform; and on account of the large underground water storage high floods seldom occur. The uniform and large minimum flow combined with fairly good dam sites gives this stream fair possibilities for moderate sized water-power developments.

Plains and headwaters provinces.—The State of New Mexico has plans prepared by Hugo March, jr., under direction of State Engineer George M. Neel in 1925, for the location of sites for two reservoirs on the head of the dry Cimarron River above Folsom and one below Folsom. Of those above Folsom, one, the Morrow, calls for a dam 120 feet high to impound 21,506 acre-feet of water and having a drainage of 45 square miles. The other is to have a dam 80 feet, impounding 11,716 acre-feet of water. Folsom in April, 1905, was devastated by a flood costing many lives. The site below Folsom known as Baker Reservoir site is considered to be admirably situated for flood control as well as for irrigation. It is located just above Valley. The dam would have a height of 80 feet and would impound 20,000 acre-feet of water.

The Commission of Drainage, Irrigation, and Reclamation for the State of Oklahoma has developed plans for 18 conservancy reservoirs on the basin of Cimarron River for flood control. These reservoirs would begin near the New Mexico State line and would extend practically to the mouth of the river. They would have a total storage capacity of 1,746,800 acre-feet, or when supplemented by those proposed in New Mexico, a total of 1,800,930 feet. This storage capacity would take care of a general rain of nearly three inches over basins of the streams upon which the reservoirs are located. To this system can be added the reservoir of the town of Okmulgee, Okla., which secures its domestic water supply from a reservoir located on a tributary stream near the mouth of the Cimarron River. The life and ultimate value of the reservoirs called for under this plan will depend largely upon the control of erosion of soil, preventing the loss of storage capacity through sedimentation. This control must largely come through maintaining soil cover and reducing corrasion of banks.

More than 20 reservoirs established for irrigation on the headwater province of the main Arkansas largely control and largely direct its normal summer flow.

APPENDIX X

PROPORTION OF FLOODS CONTRIBUTED BY DIFFERENT STREAMS IN THE ARKANSAS BASIN

W. W. Ashe, *Senior Inspector, Eastern National Forest District*

The Arkansas and White Rivers together have contributed during the 15-year period, for which data are available since 1911, 6.9 and 7.3 per cent respectively, to the flood waters of the Mississippi River as gauged at Arkansas City, Ark. Altogether these two streams have contributed on an average 14.2 per cent of the waters of major floods.

The flood waters of the White River come from all portions of the basin, but more largely from the eastern sector, since the rainfall is heaviest in this sector. (Tables 7 and 8.) The flood waters of the Arkansas River below Little Rock come chiefly from the forested Ozark region and the nearby woodland sections of Oklahoma and Missouri, although southeastern Kansas contributed a small amount.

During the period for which data are available during the last 15 years there has been the following contributions to major Arkansas River floods made by the plains streams:

	Per cent
Verdigris River	0.7
Neosho River	1.5
Canadian River	.2
Cimarron River	.2

It is evident that the contribution of the first two streams is small and that the contribution of the Canadian River, which is typical of the two remaining streams, is negligible.

A more detailed analysis shows that the origin of the flood waters on the Arkansas River is the eastern sector of the basin constituting only a relatively small portion of the entire area of the basin.

Table 7.—*Contributions of the Arkansas and White Rivers and their tributaries to the Mississippi River flood crests at Arkansas City, Ark.*

Date of Mississippi River flood at Arkansas City	Per cent of flood contributed by each river above station for measurement								
	Arkansas River, Little Rock, Ark.	Neosho River, Fort Gibson	Canadian River, Calvin	North Fork Canadian River, Weleetka	Verdigris River, Talala	Cimarron River, Guthrie	White River, Clarendon	Current River, Hargus Eddy	Current River, Mill Creek
1912									
Mar. 8 to June 7	6.2	1.6	3.0	2.4	6.2	3.1	7.0	0.5	0.4
1913									
Jan. 21 to Feb. 23	3.1						8.0	.3	.2
Mar. 27 to May 12	3.4	.1			Trace.		6.0	.2	.1
1916									
Jan. 3 to Mar. 16	5.0	.2	.4	.2	.1	.2	8.7	7.0	.5
Apr. 7 to May 6	10.2	.5	.2	.2	.2	.2	4.4	.3	.2
June 20 to July 4	14.9	7.2	.4	.5	3.1	.5	2.9		
1922									
Mar. 15 to May 27	5.8	1.5	.1	.1	.9	.1	5.9	.3	.2
1927									
Jan. 3 to May 1	9.7	1.4	.1	Trace.	.7	.1	5.5	.3	.2
All floods, 1912–1927	6.9	1.5	.2	.2	.7	.2	7.3	.5	.3

Compiled from graphs prepared by the Chief of Engineers, Corps of Engineers, U. S. Army.

TABLE 8.—*Flood flows of the Mississippi River at Arkansas City, Ark., compared with flows of the Arkansas and White Rivers and with flows of certain of their tributaries*

Date	Mississippi River flow at Arkans City, Ark.		Arkansas River: Point of observation, number of days for water to reach Arkansas City, approximate drainage area and flow												White River: Point of observation, number of days for water to reach Arkansas City, approximate drainage area and flow					
			Arkansas River at Little Rock, Ark., 3 days [1] (158,420 square miles)		Arkansas River tributaries										White River at Clarendon, Ark., 4 days [1] (25,516 square miles)		White River tributary			
					Neosho River at Fort Gibson, Okla., 12 days [1] (12,660 square miles)		Canadian River at Calvin, Okla., 13 days [1] (36,368 square miles)		North Fork Canadian River at Weleetka, Okla., 13 days [1] (13,645 square miles)		Verdigris River at Talala, Okla., 13 days [1] (3,912 square miles)		Cimarron River at Guthrie, Okla., 15 days [1] (15,335 square miles)				Current River at Hargus Eddy, Mo., 10 days [1] (2,180 square miles)		Current River at Mill Creek, Mo., 11 days [1] (1,600 square miles)	
	Flow per 1,000 cubic feet per second	Remarks	Flow per 1,000 cubic feet per second	Per cent of Arkansas City flow	Flow per 1,000 cubic feet per second	Per cent of Arkansas City flow	Flow per 1,000 cubic feet per second	Per cent of Arkansas City flow	Flow per 1,000 cubic feet per second	Per cent of Arkansas City flow	Flow per 1,000 cubic feet per second	Per cent of Arkansas City flow	Flow per 1,000 cubic feet per second	Per cent of Arkansas City flow	Flow per 1,000 cubic feet per second	Per cent of Arkansas City flow	Flow per 1,000 cubic feet per second	Per cent of Arkansas City flow	Flow per 1,000 cubic feet per second	Per cent of Arkansas City flow
1912																				
Mar. 8	1,000	--------	69	6.9	--------	--------	--------	--------	--------	--------	Low.	--------	--------	--------	45	4.5	4	0.4	5	0.5
Mar. 26	1,250	--------	53	4.2	22	1.8	7	0.6	5	0.4	9	0.7	6	0.5	97	7.8	7	.6	5	.4
Apr. 3	1,500	--------	160	10.7	37	2.5	7	.5	5	.3	16	1.1	5	.3	102	6.8	14	.9	10	.7
Apr. 13	1,850	Peak	125	6.8	70	3.8	5	.3	4	.2	30	1.6	4	.2	163	8.8	8	.4	7	.4
May 17	1,500	--------	88	5.9	2	.1	2	.1	2	.1	1	.1	4	.3	143	9.5	6	.4	4	.3
June 1	1,250	--------	30	2.4	3	.2	2	.2	2	.2	1	.1	3	.2	67	5.4	3	.2	2	.2
June 7	1,000	--------	54	5.4	2	.2	2	.2	2	.2	1	.1	4	.4	36	3.6	3	.3	2	.2
1913																				
Jan. 21	1,000	--------	80	8.0	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	70	7.0	6	.6	5	.5
Jan. 26	1,250	--------	70	5.6	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	129	10.3	4	.3	2	.2
Feb. 10	1,500	Peak	16	1.1	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	120	8.0	2	.1	2	.1
Feb. 20	1,250	--------	12	1.0	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	85	6.8	2	.2	1	.1
Feb. 23	1,000	--------	10	7.0	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	73	7.3	2	.2	1	.1
Mar. 27	1,000	--------	39	3.9	2	.2	--------	--------	--------	--------	1	.1	--------	--------	30	3.0	2	.2	1	.1
Apr. 4	1,250	--------	125	10.0	2	.2	--------	--------	--------	--------	Low.	--------	--------	--------	55	4.4	4	.3	3	.2
Apr. 10	1,500	--------	50	3.3	2	.1	--------	--------	--------	--------	1	.1	--------	--------	97	6.5	4	.3	3	.2
Apr. 22	1,850	Peak	45	2.4	1	.1	--------	--------	--------	--------	--------	--------	--------	--------	137	7.4	4	.2	3	.2
May 3	1,500	--------	19	1.3	Low.	--------	--------	--------	--------	--------	Low.	--------	--------	--------	115	7.7	2	.1	1	.1
May 10	1,250	--------	14	1.1	Low.	--------	--------	--------	--------	--------	Low.	--------	--------	--------	70	5.6	2	.2	1	.1
May 12	1,000	--------	30	3.0	Low.	--------	--------	--------	--------	--------	Low.	--------	--------	--------	58	5.8	2	.2	1	.1

1916																				
Jan. 3	1,000	--------	38	3.8	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	67	6.7	--------	--------	--------	--------
Jan. 11	1,250	--------	83	6.6	Low.	--------	--------	--------	--------	--------	--------	--------	--------	--------	101	8.1	2	.2	--------	--------
Jan. 24	1,500	--------	50	3.3	1	.1	--------	--------	--------	--------	Low.	--------	--------	--------	115	7.7	11	.7	8	.5
Feb. 12	1,900	Peak	155	8.2	10	.5	--------	--------	--------	--------	4	.2	--------	--------	287	15.1	42	2.2	29	1.5
Feb. 28	1,500	--------	58	3.9	5	.3	--------	--------	--------	--------	2	.1	--------	--------	129	8.6	5	.3	3	.2
Mar. 8	1,250	--------	58	4.6	4	.3	--------	--------	--------	--------	2	.2	--------	--------	83	6.6	4	.3	2	.2
Mar. 16	1,000	--------	34	3.4	2	.2	4	.4	2	.2	1	.1	2	.2	58	5.8	2	.2	1	.1
Apr. 7	1,000	--------	160	16.0	1	.1	3	.3	2	.2	1	.1	2	.2	34	3.4	2	.2	1	.1
Apr. 15	1,250	--------	120	9.6	5	.4	2	.2	2	.2	2	.2	2	.2	43	3.4	7	.6	5	.4
Apr. 22	1,300	Peak	140	10.8	6	.5	3	.2	2	.2	2	.2	2	.2	60	4.6	3	.2	2	.2
Apr. 25	1,250	--------	135	10.8	8	.6	3	.3	2	.2	2	.2	2	.2	62	5.0	2	.2	1	.1
May 6	1,000	--------	38	3.8	9	.9	3	.3	2	.2	4	.4	2	.2	58	5.8	3	.3	2	.2
June 20	1,000	Peak	160	16.0	27	2.7	2	.2	1	.1	12	1.2	1	.1	27	2.7	--------	--------	--------	--------
June 27	1,000		157	15.7	100	10.0	2	.2	10	1.0	42	4.2	9	.9	30	3.0	--------	--------	--------	--------
July 4	1,000		130	13.0	90	9.0	8	.8	5	.5	38	3.8	6	.6	30	3.0	--------	--------	--------	--------
1922																				
Mar. 15	1,000	--------	53	5.3	Low.	--------	1	.1	Low.	--------	--------	--------	Low.	--------	46	4.6	3	.3	2	.2
Mar. 22	1,250	--------	75	6.0	Low.	--------	1	.1	1	.1	Low.	--------	Low.	--------	74	5.9	7	.6	4	.3
Mar. 29	1,500	--------	56	3.7	61	4.1	1	.1	1	.1	29	1.9	1	.1	94	6.3	6	.4	3	.2
Apr. 25	2,500	Peak	205	8.2	72	2.9	3	.1	2	.1	55	2.2	2	.1	146	5.8	7	.3	5	.2
May 20	1,500	--------	90	6.0	10	.7	2	.1	1	.1	6	.4	1	.1	92	6.1	4	.3	2	.1
May 22	1,250	--------	60	4.8	6	.5	2	.2	1	.1	2	.2	1	.1	83	6.6	3	.3	2	.2
May 27	1,000	--------	38	3.8	5	.5	3	.3	2	.2	2	.2	2	.2	58	5.8	3	.3	2	.2
1927																				
Jan. 3	1,000	--------	(?)	--------	(?)	--------	--------	--------	--------	--------	--------	--------	--------	--------	(?)	--------	--------	--------	--------	--------
Jan. 17	1,250	Peak	11	.9	4	.3	--------	--------	--------	--------	Low.	--------	--------	--------	68	5.4	2	.2	1	.1
Jan. 25	1,000	--------	54	5.4	3	.3	--------	--------	--------	--------	Low.	--------	--------	--------	45	4.5	3	.3	1	.1
Feb. 6	1,250	--------	116	9.3	9	.7	--------	--------	--------	--------	1	.1	--------	--------	165	13.2	7	.6	5	.4
Feb. 15	1,350	Peak	40	3.0	15	1.1	--------	--------	--------	--------	2	.1	--------	--------	146	11.2	5	.4	3	.2
Mar. 1	1,250	--------	18	1.4	10	.8	--------	--------	--------	--------	1	.1	--------	--------	77	6.2	3	.3	2	.2
Mar. 9	1,100	--------	26	2.4	5	.5	--------	--------	--------	--------	Low.	--------	--------	--------	.50	4.5	2	.2	1	.1
Mar. 24	1,250	--------	134	10.7	12	1.0	2	.2	1	.1	1	.1	1	.1	61	4.9	4	.3	3	.3
Apr. 5	1,500	--------	37	2.5	50	3.3	2	.1	1	.1	5	.3	1	.1	113	7.5	5	.3	3	.2
Apr. 21	[2] 1,900	--------	610	32.2	33	1.7	2	.1	1	.1	10	.5	1	.1	160	8.4	11	.6	8	.4
May 1	2,500	--------	350	14.0	99	4.0	2	.1	1	--------	44	1.8	2	.1	402	16.1	26	1.0	19	.8
May 1	1,350	(3)	350	25.9	99	7.3	2	.1	1	.1	44	3.3	2	.1	402	29.8	26	1.9	19	1.4
May 7	1,250	(3)	150	12.0	56	4.5	2	.2	2	.2	25	2.0	2	.2	230	18.4	7	.6	5	.4
June 3	1,000	(3)	65	6.5	8	.8	2	.2	1	.1	1	.1	1	.1	104	10.4	6	.6	3	.3

[1] Number of days required for the water to travel from point of measurement to the Mississippi River. The flow shown for each contrasted stream is that of a date adjusted for this lag in order to render a true comparison of the flow contributed.

[2] The record of "Apr. 21—1,900,000 cu. ft./sec.," is the last one made before the levees commenced breaking, thereby lowering the river. The figure "May 1—2,500,000 cu. ft./sec." s an estimate of what the flow would have been had the river been confined within the levees.

[3] Actual record.

Compiled from graphs of stream flow prepared by the Chief Engineer's office, Corps of Engineers, U. S. Army.

The White River with a basin (above Clarendon) which constitutes only 2.2 per cent of that of the Mississippi River drainage, has contributed on an average of 7.3 per cent to the flood waters of the Mississippi River at Arkansas City since 1911. Its average contribution, however, is not so significant as its contribution to particular floods. It contributed

	Per cent
To the flood of Jan. 26, 1913	10. 3
To the flood of Feb. 12, 1916	15. 1
To the flood of Feb. 6, 1927	13. 2
To the flood of May 1, 1927	29. 8
To the flood of May 7, 1927	18. 4

If the White River is considered with the Arkansas the two streams have frequently contributed jointly more than 20 per cent and in one case as much as 60 per cent of the flood waters of the Mississippi. An analysis of the origin of the flood waters of the Arkansas River Basin indicates that except the Neosho and nearby streams in eastern Oklahoma and extreme southeastern Kansas only a relatively small proportion of flood waters originate to the west of the Ozarkian province. Data are not available for determining the exact proportion of flood waters contributed by that portion of the Arkansas River proper located within the Ozarkian province, but since the Cimarron River at Guthrie and the Canadian River at Calvin each contributes on an average less than two-tenths of 1 per cent to Mississippi flood waters and their combined flow has exceptionally amounted to as much as 1 per cent of the Mississippi flood flow, the contribution of the headwaters of the Arkansas River proper above the mouth of the Neosho will probably exceptionally exceed this amount.

The Neosho, which contributes 1.5 per cent of flood waters, is essentially on the western edge of the Ozarkian province. The Verdigris occupying the adjoining basin at the extreme eastern edge of the plains region contributes an average of 0.7 per cent. It is doubtful, consequently, if the headwaters of the Arkansas River directly outside of the Ozarkian province will contribute, on an average, as much as 2 per cent of the total flood waters of the Mississippi River and whether the total contribution of the Arkansas River system outside of the Ozarkian province ever amounts to as much as 10 per cent.

During the flood period of April 21, 1927, when the Arkansas River at Little Rock contributed 32.2 per cent of the Mississippi flood waters at Arkansas City, the Canadian and Cimarron Rivers contributed a combined total of less than 0.2 per cent. Since the Verdigris contributes much less than the Neosho, the contribution from the main Arkansas above the mouth of the Verdigris must, as in the case of the Canadian, have been extremely small. During the floods of 1927 it is improbable that at any time the contribution of the plains and headwaters streams exceeded 10 per cent of the total flood waters of the Mississippi. At this same date the White River contributed 8.4 per cent. Consequently if that portion of the Arkansas proper within the Ozark region (including the Neosho) contributed 22.2 per cent, the total contribution of the Ozarkian province to the Mississippi flood was in excess of 30 per cent, from less than 5 per cent of the contributing basin of the Mississippi River.

The flood crests of the White River and the Arkansas reach the Mississippi at the same time. It requires a flood crest three days to pass into the Mississippi River from Little Rock at the eastern end of the Ozark Valley on the Arkansas River, and four days for a flood crest to pass from Clarendon on the White River, occupying the same relative position as Little Rock. Twelve days are required for a flood crest at Fort Gibson on the Neosho to reach the Mississippi River; 13 days from Calvin on the South Canadian; 13 days from Weleetka on the North Canadian; 13 days from Talala on the Verdigris, and 15 days from Guthrie on the Cimarron. Flood crests on these streams consequently flatten out considerably before reaching the Mississippi, and in fact before reaching Fort Smith and Little Rock. Or in the case of a general rain which does not exceed 13 days, the flood crests on these streams largely follow the flood crest of the White and that on the lower part of the basin of the Arkansas in place of augmenting its crest. But in case of a general rainy period, more prolonged than 15 days, or of a storm moving slowly from the west, the flood crests of these streams will augment the later crest of the waters from the Ozark region. Moreover, the flood crests of all of these plains streams are synchronized and, in the case of a high, prolonged storm affecting them, their combined waters add to the prolonged crest from the Ozark province.

APPENDIX XI

DESCRIPTION OF FLOODS IN THE ARKANSAS BASIN

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The following is a very incomplete list of the destructive floods upon the tributaries of the Arkansas River and upon the head of the main stream prior to 1927:

It seems that about half of the floods in the lower stretch of the Arkansas River have occurred in May and June, none in September, and very few in October and November. In the Black and White Rivers floods are frequent from December to June with few during the remainder of the year, the greatest number in the Black, in April; and the greatest number in the White, in May. The records for the Cache and the St. Francis Rivers are for far too short a time to draw definite conclusions, but the short records seem to indicate that floods are more frequent from December to June, the same as in the Black and the White.

The greatest flood in the Arkansas River of which we have any definite knowledge occurred in May, 1844, the stage being 32.6 feet as given in a statement in the Arkansas Gazette of May, 1884. The next highest was 31.7 feet in June, 1833, our information concerning this flood also being due to the Gazette.

The highest stages in these floods were carefully given with reference to the top of "Little Rock," by which the height was easily found on the present gage. The highest stage at Little Rock since the present series of readings began was 27.9 feet in May, 1892, the next highest, 27.8 feet in June, 1904. The highest at Fort Smith, Ark., since 1887 was 35.4 feet in May, 1898, the highest at Dardenelle, Ark., since 1890 was 29.7 feet in January, 1916, the highest at Pine Bluff, Ark., since 1906 was 29.6 feet in February, 1916. The variation in the dates of highest stages is fully accounted for by the variation in the amounts of rainfall between Fort Smith and the different stations and variations in the stages in the Mississippi River. The highest stage recorded at Newport (White River) since readings began in 1890 was 34.3 feet in February, 1916, the next highest, 33.9 feet in August, 1915. The highest stage we have any knowledge of at Marked Tree, Ark., on the St. Francis River, was 24.2 feet in April, 1912.

Floods in the Arkansas River are caused by heavy rains in southern Kansas, Oklahoma, and western Arkansas, not by melting snow as was formerly supposed. The rains causing floods in the Red River occur in Oklahoma, northeastern Texas, southwestern Arkansas, and western Louisiana. These rains are mainly of the Plains States type, heaviest from March to June. The rains causing the floods in the remaining rivers in Arkansas are of the Gulf States type, heavy from December to June. The difference in the types of rainfall accounts for the larger number of floods in the Arkansas and Red Rivers occurring from March to June, while floods are frequent from December to June in the other rivers of the State.

IMPORTANT FLOODS ON ARKANSAS RIVER AND TRIBUTARIES

The flood of June 3–5, 1921, on head of the main Arkansas River.—Between June 2 and June 5, 1921, heavy rains of an intensity to justify the term "cloud-bursts" in the foothill region of the Arkansas Valley in Colorado caused the severest flood in the valley since its settlement. Flood conditions prevailed during the entire period, but there were three distinct floods in the upper valley. The first

flood was caused by heavy rain on Dry Creek just above Pueblo on the night of June 2; the second was the main flood, which occurred during the night of June 3; and the third was that due to the breaking of the Schaeffer Reservoir, on Beaver Creek, on the morning of June 5.

The flood was remarkable for the very small area covered by the rainfall that was its chief cause, and for the swift rise of the river to an unprecedented stage and its almost equally rapid fall. The swift rise and fall indicated very great flood discharges of the tributary streams, which drain a mountainous country of steep slopes. The total discharge of the main flood was less than 90,000 acre-feet.

The entire Arkansas Valley from Florence, 30 miles west of Pueblo, to the State line was severely affected, and the loss of life and property was heavy.

Property losses in Arkansas River flood of June, 1921

Federal, State, and county property	$900, 000
Municipal property	800, 000
Real estate (city and town)	3, 420, 000
Personal property (city and town)	3, 575, 000
Farms	3, 675, 000
Irrigation works	1, 275, 000
Railroads	4, 275, 000
Public utilities	500, 000
Other property	250, 000
Total	19, 080, 000

A report to the Pueblo City Council stated that 510 dwellings were washed away, 98 buildings wrecked, and 61 buildings washed from their foundations. Loss of life was in excess of 78.

The first flood of authentic record on the head of the Arkansas occurred in 1855, after a winter of very heavy snowfall, although the flood itself was probably caused by hard rain during a period of melting snow.

The next flood recorded was that of June 11, 1864, caused chiefly by heavy rains.

A flood of considerable magnitude in the Arkansas and Purgatory near Las Animas occurred July 20–25, 1886. The rainfall at Las Animas was 3.36 inches during July 24 and 25 and 4.66 inches for the month, or more than twice the normal. This flood was not severe at Pueblo, as the newly established gauging station showed a maximum of only 3,080 second-feet on July 21.

A flood during May, 1889, caused the removal of Fort Lyon to a point 17 miles farther west. The rainfall for May was 4.84 inches, as compared with a normal of 2 inches.

No unusual floods are recorded after 1889 until 1893. Although this was the second driest year in 35 years, as shown by records of precipitation at Pueblo, the flood on July 26, 1893, seems to have been the fourth in magnitude in three-quarters of a century.

The rainfall at Pueblo was 1.36 inches on July 26 and 0.22 inch on the 27th. The precipitation for the year was 6.84 inches, as compared with a normal precipitation of 12.50 inches.

The most destructive flood in the history of the upper Arkansas Valley prior to the flood of 1921 occurred May 30, 1894. Heavy

precipitation on May 30 and 31 extended over the Arkansas drainage basin, taking the form of snow at the higher elevations, notably on Pikes Peak and the mountains in the upper end of the basin. The rainfall on the 30th and 31st at Pueblo was 3.02 inches and at Canon City on the 29th and 30th 5.06 inches. Five lives were lost in Pueblo, and damage amounting to nearly $2,000,000 was done to property.

The lower Arkansas Valley in Kansas was visited by very severe floods during 1904, but they did not reach the upper valley. Between Wichita and Arkansas City the flood of July 9, 1904, was the severest known. For 10 days before that date the maximum discharge at Pueblo was 1,520 second-feet. On September 30, 1904, the severest flood known occurred on Purgatory River. This flood caused a great amount of damage on Arkansas River below the mouth of the Purgatory.

The next serious flood in the Arkansas Valley, and the last one before 1921, occurred October 19–21, 1908, and affected the area east of La Junta, Colo. It was due to heavy rains. Practically all the rain was believed to have fallen in eight hours during the night of October 18. That this flood did not affect the upper river is shown by the fact that the maximum discharge of the Arkansas at Pueblo for a week prior to the flood was only 298 second-feet, which shows that there was no flood at Pueblo within the time it would have taken for flood flow there to reach La Junta by October 19.

Purgatory River flood.—The largest and by far the most destructive flood recorded in the history of Purgatory River occurred from 10 p. m. September 29, to 8 a. m. September 30, 1904. All the city bridges in Trinidad were washed away or badly damaged, the city water supply was cut off by the destruction of the main pipe line, the electric light plant was disabled, telephone communications were cut off, and railway services were entirely abandoned. Public, private, and corporate property was damaged to the extent of $650,000. No lives were lost, an almost miraculous fact, considering the suddenness and magnitude of the flood and its occurrence in the night.

The drainage basin is about 120 miles long and from 30 to 40 miles in width and comprises an area of about 3,390 square miles.

The upper and mountainous part, lying above Trinidad has an area of 742 square miles, the country rock being mainly shales and sandstones, with some igneous rocks. The surface is carved into valleys where the formation is shale and into canyons where the formation is more resisting. The vegetation of the lower half of this area is largely cedars and bunch grass; of the upper portion pine, cedar, fir, and the usual Colorado mountain flora. Ground storage of sudden rain in this part of the basin is small, owing to the shallow and steep slopes.

The lower part, having an area of 2,640 square miles, extends from Trinidad to the mouth of the river. The soil here is largely from decomposed shale, with some from sandstones and limestones. The vegetation consists of cedars, bunch grass, cactuses, etc. Surface storage is small.

This is the principal southern tributary of the Arkansas River. It is a characteristic stream of eastern Colorado, heading in the lower mountains, flowing across the plains, and carrying little water except during floods. In the spring the channel carries a moderate volume of water, but as summer approaches this is gradually diminished by irrigation and natural conditions until the channel is practically dry. The volume of water contributed to the Arkansas by this stream is so small that it has scarcely an appreciable effect upon the discharge of the Arkansas, except at times of excessive local rainfall. Its flow is very erratic; the discharge may vary from a few second-feet to several thousand in a few hours.

The mean annual precipitation over the Purgatory River drainage basin varies from about 13 inches near the mouth to about 23 inches near the source, the September average from source to mouth varying from about 1 inch to 1.2 inches.

The following table gives the daily depth of rainfall at or through places in this basin during the flood period from September 26 to 30, 1904:

Precipitation, in inches, preceding Purgatory River flood, 1904

Place	Elevation in feet	Sept. 27	Sept. 28	Sept. 29	Sept. 30	Total
Trinidad	6,000	0.18	0.72	1.92	3.13	5.95
Hoehne	5,271		.10	3.00	2.15	5.25
Clear View	9,500	.48	2.03	1.36		3.87

The rainfall was heaviest along the southern mountain watershed of the Purgatory River above and below Trinidad, and traveled slowly from west to east. This movement, together with the physical character of the southern portion of the drainage basin, accounts for the immense amount of water which arrived at the mouth of the Purgatory River. The rainfall of the upper tributaries reached Trinidad almost simultaneously with the greater portion of the flood which came into the Purgatory River from Long Creek, about 6 miles above Trinidad.

Neosho River flood.—The Neosho River is a stream of middle Kansas noted for its destructive floods of the local prolonged type. During both 1927 and 1928 there were exceptionally destructive floods.

The 1904 floods on Neosho River were greater in number, height, and destructiveness than were ever before known on this stream up to that year. The flood of 1885 was the largest prior to that of 1904. Although there are no definite records of the height reached by the 1904 flood, there are quite a number of well-defined flood marks along the river, which show that the crest of the flood of July 10, 1904, reached about a foot higher than the 1885 flood.

The upper part of the watershed is hilly pasture land, from which the water flows rapidly. The central and lower part is rolling, cultivated land. There are no forests on the watershed, but narrow strips of trees are found along the greater part of the stream. Nearly all the country between the Neosho and Cottonwood Rivers in the vicinity of Emporia was flooded and the crops destroyed by the 1904 floods. The railroads along the river and crossing it were tied up for several days. The Neosho branch of the Missouri, Kansas, & Texas Railroad, which extends from Junction City to Parsons, suffered severely, but none of the bridges were washed away.

Verdigris River floods.—Floods are common on Verdigris River. Rarely a year passes without a flood that causes overflow of some of the bottom lands along the river. There were five floods on this river from April 26 to July 10, 1904, that reached a stage of more than 27 feet above low water at Independence, and two of these reached a stage of more than 41 feet above low water.

Considerable damage was done by the floods on the lower reaches of this river in the vicinity of Coffeyville. A portion of the city was flooded, in addition to the loss of crops in the bottoms. The high water decreased from the Kansas and Oklahoma (then Indian Territory) State line to the mouth of the stream. The flood of 1904 had a maximum rate of discharge at Independence of 50,400 cubic feet per second and the height of the flood above low water was about 40 feet.

Cloud-burst floods on head of Arkansas River.—Between 6 and 9 p. m., May 27, 1922, a very heavy cloud-burst rain above Templeton

Gap, 5 miles northwest of Colorado Springs, Colo., produced a flood that caused much damage to property in and near Colorado Springs.

Northeast of Colorado Springs is a semicircular range of hills, which rise abruptly from the plains and reach an altitude 800 feet higher than that of Colorado Springs. The hills are of rocky formation with shallow soils and support little vegetation. They inclose a basin having a narrow outlet called Templeton Gap. A rancher living above the gap estimated from the amount of water caught in a pail standing in his yard that the rainfall was 7 inches. A peculiarity of the flood was the mud balls left in the channel. These were composed of black clay or gumbo and ranged from 6 to 30 inches in diameter. So fine was their texture that they closely resembled black bowlders. The area above Templeton Gap is subject to frequent cloud-bursts, but residents state that this flood was the greatest in 50 years or more.

From April 22 to 24, 1905, 2.5 inches of rain and snow fell at Trinidad, Colo., and a greater depth on the mountains, causing a freshet in Purgatory River for several days. The stream has a fall of 43 feet per mile in the vicinity of Trinidad, and the sandy loam banks, softened by the rains, disappeared rapidly into the river. Many acres of fertile bottom land and thousands of feet of railway were swept away. The stream in places shifted its channel from one side of the valley to the other, necessitating the moving of some of the bridges.

Floods of the Cimarron.—The most disastrous flood on the upper part of the Dry Cimarron River was the Folsom flood of April, 1905, costing many lives and almost totally destroying the town. This flood clearly indicates the treacherous and dangerous character of this river. It was produced by a rainfall of practically 4 inches which occurred immediately preceding the flood. The precipitation for August is not infrequently in excess of 4 inches in this portion of the basin though not so concentrated. For August, 1907, it was 5.53 inches. For August, 1910, it was 5.38. Although the average rainfall for the year at Folsom is only 19 inches, three-quarters of it normally falls during five summer months.

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